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RAPID SURVEY TECHNIQUE FOR ESTIMATING COMMUNITY AIR POLLUTION EMISSIONS

Guntis Ozolins, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

October 1966

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service

A RAPID SURVEY TECHNIQUE FOR ESTIMATING COMMUNITY AIR POLLUTION EMISSIONS

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
National Air Pollution Control Administration
Raleigh, North Carolina
October 1966

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PREFACE

The documentation of air pollution sources and emission strengths within a community provides the basic framework for air conservation activities. The extent of the source surveys used in obtaining this information depends greatly on individual objectives and available resources. Comprehensive emission inventories, including field visits, plant surveys, questionnaires, and stack sampling, have been conducted in a number of major metropolitan areas. The budgetary and personnel resources required for such programs, however, are beyond the scope of many communities. This rapid survey method for conducting an emission inventory has been prepared as a means of providing reasonable working estimates with limited resources.

The method presented herein utilizes information readily available in most communities to provide reasonably accurate, yet rapid, estimates of the major air pollutant emissions of an urban area. The method does not require extensive plant surveys or source sampling procedures involving high levels of technical competence and large expenditures. It is presented in a stepwise format, including discussions of basic assumptions, aimed at guiding a person of moderate professional training. Field trials of the method in communities with 350,000 and 2,000,000 inhabitants required 3 and 6 weeks, respectively, for such a person to complete the survey and basic report.

An important feature of this method is the concept of reporting zones. Emissions are assigned to the general geographical localities where they occur, rather than reported as total values for the entire metropolitan area. In this manner, areas of high emission strengths are identified and the distribution patterns of the different pollutants within the study area may be estimated.

Emission inventory data have many applications in air conservation programs. They can be used effectively in metropolitan planning, pollution abatement, initiation of sampling programs, interpretation of sampling results, and estimation of anticipated pollutant concentrations in the atmosphere.

Metropolitan Planning: The emission maps of the community, in terms of tons per day of pollutants discharged on a sub-area basis, can provide a guide for future metropolitan planning and zoning by pinpointing overburdened areas and their relation to populated zones and areas affected during periods of minimum natural ventilation.

Pollution Abatement: As an index of relative importance, the information resulting from the emission survey becomes a useful guide for a community pollution abatement program. It can indicate the degree of need for intensive abatement of sources in certain geographic areas, of specific point sources, or of classes of emitters of specific pollutants. The information is useful in predicting the approximate effect of specific regulations on emissions and in pointing out where the "control dollar" may have the optimum effect.

Sampling Programs: Presentation of emission data on the basis of reporting zones can provide a basis for optimum location of air quality sampling stations in a community.

Estimation of Pollutant Concentrations: Through the development of mathematical meteorological diffusion models, based on the emissions of contaminants, the ambient concentrations of these pollutants in various areas of the community may be estimated. Seasonal variations of these concentrations can also be estimated with respect to the climatic effect on the use of fuels for space heating and the attendant increase in pollutant emissions.

The rapid survey technique presented herein is not meant to replace more detailed surveys where they are needed and where more extensive resources are available. The rapid method will provide reasonable information for making intelligent decisions in air conservation programs in many communities at an earlier time than might otherwise be possible. With rapid method a beginning can be made today—a beginning that should be carefully reviewed and modified with passage of time and the gathering of more detailed information.

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ABSTRACT

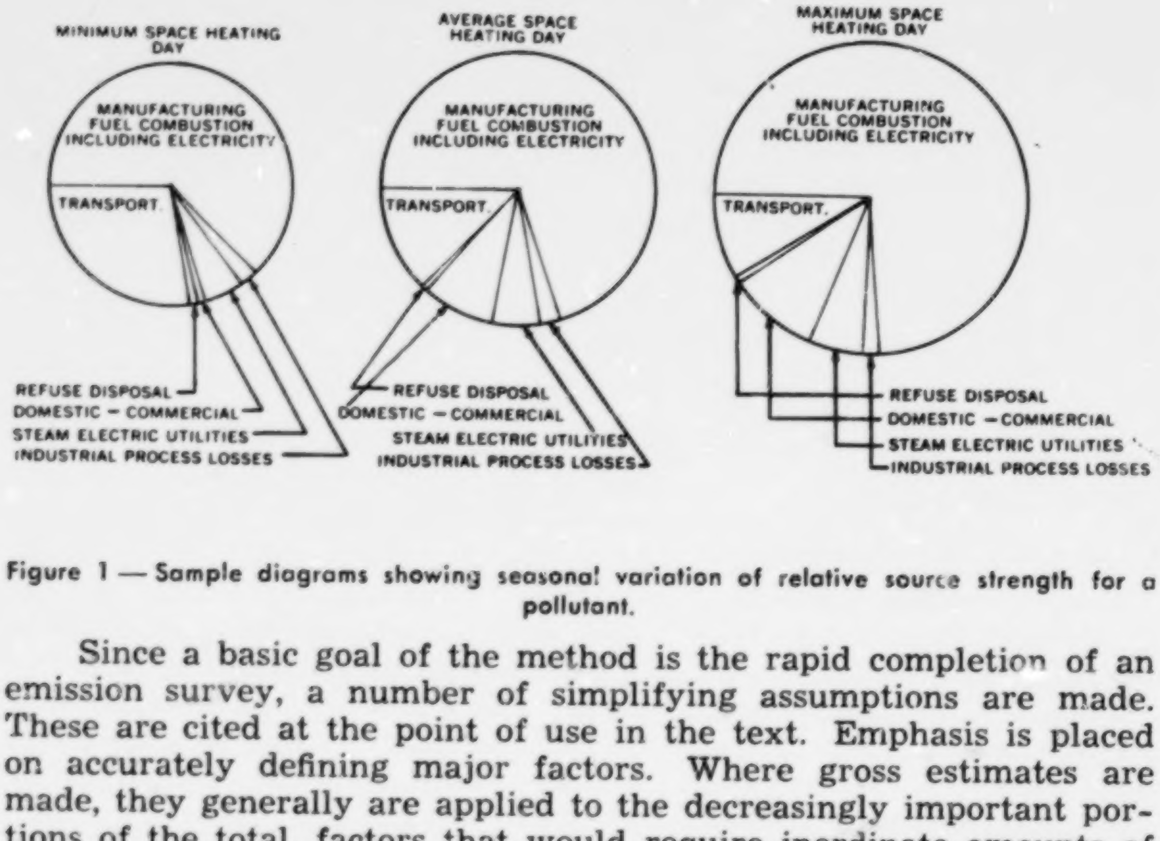
A method is presented for estimating rapidly the major emissions of air pollutants in a community. The method is based on information that is readily available in most urban areas; it does not entail extensive surveys or sampling procedures. Application of this survey method will yield a series of tables, maps, and diagrams that indicate (1) the weights of emissions of selected pollutants, by year and by season; (2) the relative importance of various fuels and types of sources in producing the emissions; (3) the relative amounts of pollutants emitted in various geographic sub-areas of the community. Such information constitutes a useful tool for developing an air conservation program.

AN INTRODUCTION TO THE RAPID SURVEY METHOD

The categorizing of a community's air pollution emissions as proposed herein will produce a series of tables, maps, and diagrams that indicate the following:

1. The annual total and seasonal weight of emissions of selected pollutants.
2. The relative importance of various fuels and types of sources in producing the emissions.
3. The relative weights of pollutants emitted in various geographic sub-areas of the community.

Such information provides an effective tool for developing an air conservation program. The relative importance of various contributors to the community's present air pollution problem can be visualized, as indicated in Figures 1 and 2. On the basis of such data, planners can project the possible increase of air pollution in the area in future years.


MINIMUM SPACE HEATING DAY
MANUFACTURING FUEL COMBUSTION INCLUDING ELECTRICITY
TRANSPORT
REFUSE DISPOSAL
DOMESTIC – COMMERCIAL
STEAM ELECTRIC UTILITIES
INDUSTRIAL PROCESS LOSSES
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STEAM ELECTRIC UTILITIES
INDUSTRIAL PROCESS LOSSES

Figure 1 — Sample diagrams showing seasonal variation of relative source strength for a pollutant.

Since a basic goal of the method is the rapid completion of an emission survey, a number of simplifying assumptions are made. These are cited at the point of use in the text. Emphasis is placed on accurately defining major factors. Where gross estimates are made, they generally are applied to the decreasingly important portions of the total,. factors that would require inordinate amounts of time to define accurately.

Four general classes of pollutants are specificially considered: oxides of sulfur, oxides of nitrogen, hydrocarbons, and particulates.

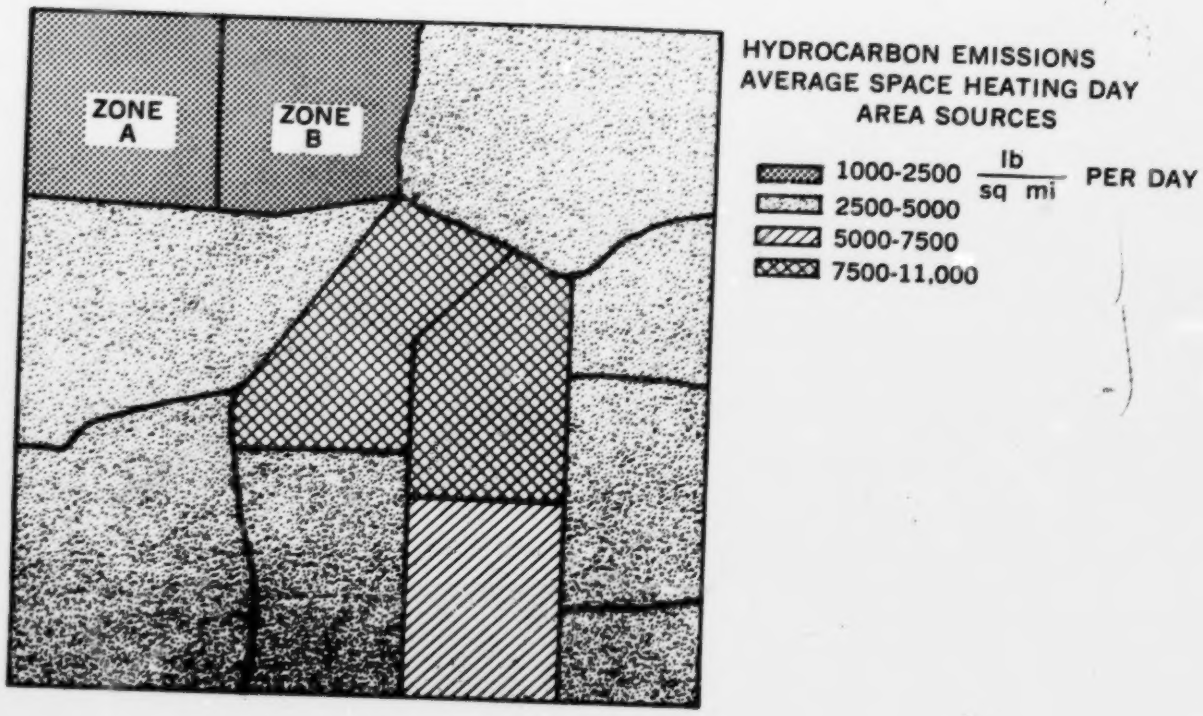

Figure 2 — Sample emission map of a community.

Although the rapid survey technique stresses the estimation of the emitted weights of these pollutants, similar techniques may be used for other pollutants, such as carbon monoxide, if their estimation is of particular concern in a given community and if appropriate information is available.

The emitted weight of each pollutant can be subdivided among the following four general categories of sources:

1. Stationary combustion sources.
2. Mobile combustion sources.
3. Refuse combustion sources.
4. Industrial and commercial process loss sources.

Stationary combustion sources include all structures, whether large or small, in which fuels are burned to provide space heating, process heat, and power. Mobile combustion sources are primarily motor vehicles, although the contributions from other modes of transportation, such as railroads, ships, and airplanes, may sometimes be important. Refuse combustion sources include municipal incinerators, open burning dumps, and their smaller counterparts—industrial and domestic incinerators and backyard open burning. Industrial process losses are emissions of pollutants generated by the process itself rather than by the combustion of fuels to supply heat or power for the process.

Seasonal variations in emissions of pollutants from these sources can be estimated. The major cause of such variation is the cold-weather use of fuels to provide space heating. This increase in fuel usage is generally superimposed on the relatively steady day-to-day use of fuels to generate electricity, to provide heat for industrial processes, and to operate motor vehicles.

Even with such categorizing of general sources of pollution, an urban area initially appears to be an overwhelming complex of pollution sources. The structures from which pollution is emitted are numbered in the thousands. Additional thousands of sources, such as automobiles, are mobile. All of the sources, however, can be divided into a relatively small number of groupings by type and geographic location, and the estimation of their aggregate pollution emissions is thus simplified. For example, similar types of structures tend to clump together. Substantial areas in a community are primarily residential, commercial, or industrial, and these areas are readily located from land-use and zoning maps.

These differences in land usage are utilized in dividing the study area into geographic subdivisions having internal consistency. Major residential areas are treated as individual, homogeneous sub-areas, as are major industrial and commercial areas. Such subdivision not only aids materially in delineating areas from which pollution is being emitted, but greatly simplifies the calculation of emissions from the thousands of similar small sources within the area. These are collectively referred to as an area source.

In addition to the area sources, a community usually contains a relatively small number (usually 10 to 50) of major fuel users or large process industries, which are generally well known or easily delineated. These large individual sources are referred to as point sources. With respect to their potential emissions of individual pollutants, such point sources are usually equivalent to hundreds or thousands of the smaller units that comprise the area sources. The use of fuels by the point sources and, in some case, their process losses, can be obtained with relative accuracy, rapidity, and ease.

A community tends to divide into areas of homogeneous uses of fuel, just as it tends to divide into areas of homogeneous land use. Whether a given residential area primarily burns coal, oil, or gas for heat is often a function of age. Geographically the older residential areas tend to be near the community's core, and the newer areas tend to be in the suburbs. Various types of fuel tend to have preferential use, depending on the location of the community and the nature of the user. For example, residual fuel oil is usually a major fuel only in a seaport or petroleum refining area. Furthermore, the physical nature of residual fuel oil is such that it is usually used only in large boilers, such as those for the generation of electricity, or in large industrial and commercial establishments. The chemical composition of a fuel also tends to be relatively uniform in a given locale. The coal used will usually have been mined in the nearest major coal field and thus will contain relatively uniform percentages of ash and sulfur.

Obtaining information about fuels is also simplified by the fact that fuels can be brought to a community and distributed by only a limited number of transportation methods and firms. The usual transportation methods, of course, are by truck, railroad, and ship to central distribution points. Gas is generally distributed by a public utility.

Point sources usually account for over 50 percent of a community's total fuel usage and for an even greater percentage of specific individual fuels that are used preferentially in large power plants. Since this portion of the fuel use can be specifically defined with respect to location and type, only a minor portion of the fuel usage must be distributed among the various area sources. Thus, although various estimations are applied in the survey technique, the grosser ones are limited to the minor rather than major portions of the fuel use.

In one typical trial application of the survey method, 70 percent of all the heat and power supplied by fossil fuels was produced by burning coal and residual fuel oil. Approximately 85 percent of the total coal usage and 73 percent of the total residual oil usage was assignable to the specific location of use. In this same community approximately 70 percent of the sulfur dioxide, 37 percent of the oxides of nitrogen, and 62 percent of the particulates were definable as coming from specific major fuel users and refuse disposal sites. The remaining emissions of individual pollutants were apportioned fairly accurately to various types of area sources and among various geographic subdivisions by applying available information on the use of fuels in domestic, commercial, and industrial structures and on their locations within the community.

Although fuel usage may be determined and apportioned to geographic subdivisions, translating this fuel usage into weights of emission and determining similar emissions from processes depends on the availability of average emission factors relating to a wide range of sources. Such factors are provided in Appendix F. Although these average emission factors may be grossly in error when applied to an individual source, they provide reasonably accurate estimates when applied to the relatively large number of similar sources in an urban area. The resulting calculated weights of emissions allow fairly accurate relative comparisons, even where the absolute magnitudes of the emissions are subject to question.

Finally, the completion of this type of emission survey is simplified and the possible inaccuracies greatly reduced by the availability of substantial sources of information about most of the larger American communities. Detailed census information is available on the domestic use of fuels for communities as small as 2500 population. The Bureau of Census also supplies information on the use of fuels, by type of industry, in urban areas having over 40,000 manufacturing employees. Other useful information is readily available from public utilities, local and state government agencies, and industrial associations. Such sources of information are pointed out throughout the text and are listed for easy reference in Appendix A.

SUBDIVISON OF THE STUDY AREA INTO REPORTING ZONES

The scope of the survey should be established at the beginning of the study. This will include determining the geographical boundaries of the study area, the pollutants to be investigated, and the desired detail of the study.

The purpose of reporting pollutant emissions by geographic zones of the study area is to provide information on the distribution of pollutant emissions within a community. When areas that are relatively uniform in the makeup of air pollution sources are selected as reporting zones, the emission rates of pollutants may be expressed in terms of pounds or tons per unit area and comparisons may be made among the different zones or areas.

Zones should be selected on the basis of common characteristics such as land-use patterns, fuel-use patterns, topography, and population density. Since a considerable amount of needed data is available on a census tract basis, it may be beneficial to keep census tracts intact—grouping census tracts into zones. When land-use and zoning patterns are considered, the resulting zones are either primarily residential, commercial, or industrial. In subdividing residential areas into zones, population density as well as housing data are important to delineate areas that are primarily single-family residential from large apartment house areas. The differences in fuel types used in these areas can thus be defined. Integral areas of high industrial or commercial activity should not be subdivided, but included in one zone. For example, the central business district should maintain its identity and be contained in one zone.

Choice of number of zones will determine the relative size of zones or vice versa. Use of extremely large zones will defeat the purpose of zone reporting; use of a multitude of small zones will complicate procedures without significantly increasing the validity or utility of results. Preliminary experience indicates that zones should be approximately 2 to 10 square miles in area. Although one should attempt to keep zones somewhat similar in size and shape, the zones in the outlying sections of a metropolitan area may be larger than in the highly urbanized sectors. If the study area is a very large metropolitan area or a county, it may be necessary to increase both the size of zones and the number of zones. Irregular or elongated shapes should be avoided, unless such configurations are necessary to pinpoint areas of high emission strengths. The influence of significant point sources will be shown most accurately if they are oriented toward the center of reporting zones.

The steps involved in the preparation of a reporting zone map may be summarized as follows:

1. Obtain or draw a map of the study area showing natural features such as shorelines, rivers, lakes, major arterial

streets, and political boundaries. This map will form the mat on which reporting zones will be delineated and results presented.

2. Delineate census tracts on this map. Since much of the available information is based on census tract data, it is unwise to divide the tracts.
3. Subdivide the area into zones (grouping census tracts) on the basis of common characteristics such as land-use and fuel-use patterns.
4. Where indicated, subdivide the land-use patterns on the basis of subgroup factors, such as population density in residential areas.

COLLECTION AND USE OF PRIMARY INFORMATION

STATIONARY COMBUSTION SOURCES

All major fuel types used for combustion purposes by stationary sources should be included in the survey. Generally, these consist of coal, residual and distillate fuel oil, and gas; other fuels, such as wood, should be considered if they are used in significant quantities within the study area. In addition to the quantity of fuel burned, the chemical composition of fuels also influences the emission rates of certain pollutants. Factors of importance are the ash content of coal and sulfur contents of all fuels. These components should be determined for subsequent emission-rate calculations. (See "Calculation of Pollutant Emissions.")

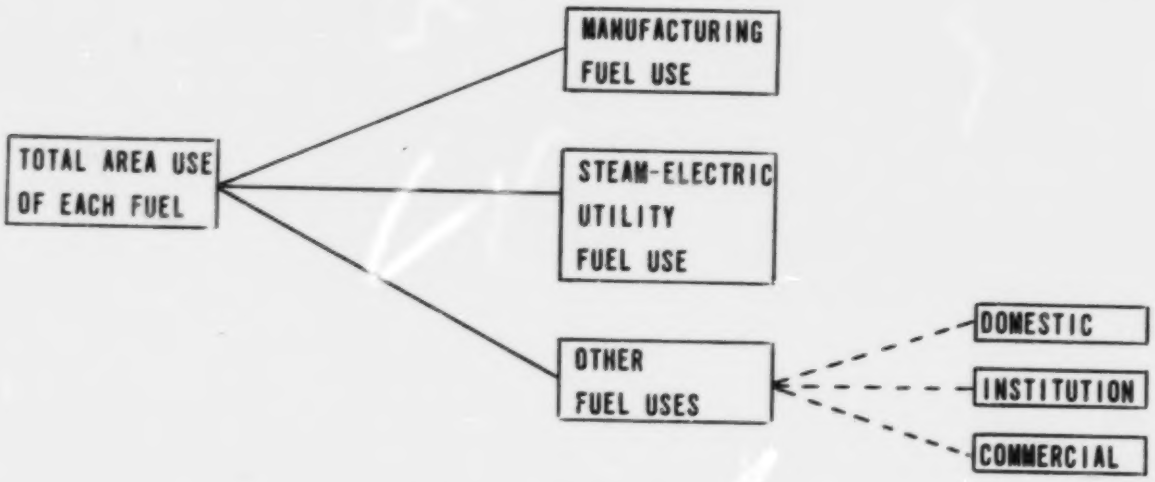

Figure 3 — Fuel use categories.

The individual fuels used in all stationary combustion sources may be subdivided according to user categories as shown in Figure 3. A breakdown of total fuel consumption by these user categories allows the use of emission factors developed specifically for each source catgory. Consideration of the gross differences among these categories in firing equipment and practices results in better estimates of pollutant emissions. Subdivision of fuel use by user categories is also needed for determining fuel-use rates and the distribution of fuel use to reporting zones.

To define as accurately as possible the quantities of air pollutants released and the geographical locations of these discharges in a community, you should further subdivide the fuels consumed by each of the user categories into those burned by point and by area sources. Establishments that individually use vast quantities of fuels and may therefore emit large amounts of pollutants are defined as *point sources.* The remaining fuel use is considered to be by the multitude of smaller fuel users or *area sources* (see Figure 4).

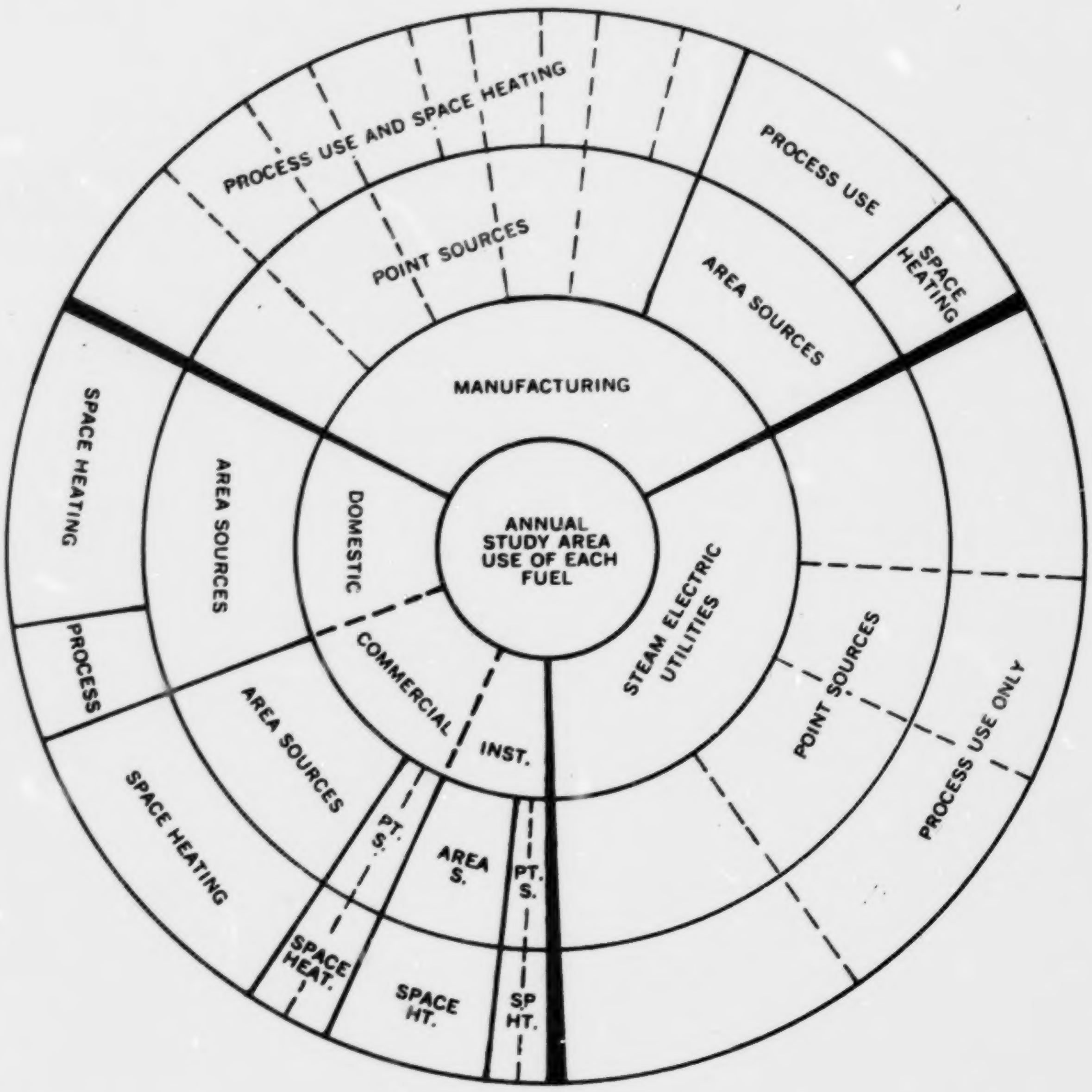
PROCESS USE AND SPACE HEATING
PROCESS USE
SPACE HEATING
POINT SOURCES
AREA SOURCES
MANUFACTURING
SPACE HEATING
AREA SOURCES
DOMESTIC
ANNUAL STUDY AREA USE OF EACH FUEL
STEAM ELECTRIC UTILITIES
PROCESS
COMMERCIAL
INST.
POINT SOURCES
PROCESS USE ONLY
AREA SOURCES
SPACE HEATING
PT. S.
AREA S.
PT. S.
SPACE HEAT.
SPACE HT.
SP HT.

Figure 4 — Subdivision of total fuel use by user categories and type of use.

Generally, a relatively few concerns in a community (10 to 50, depending on community size) account for more than 60 percent of the total community consumption of fuels. Usually the point sources consist of a few large manufacturing concerns and all of the steam electric utilities in the area. On occasion, an establishment classified as institutional or commercial may also be included among the point sources. Examples are university heating plants, large government buildings, hospitals, and heating plants serving a composite of commercial buildings. Any concern—manufacturing, institutional, or commercial—using more than 2 percent of any fuel should be considered as a point source. The 2 percent is suggested as a guide, not as a definite limit.

Each of the point sources should be considered individually to determine the exact types and quantities of fuels used, seasonal variations in fuel use, types of firing equipment, effectiveness of control equipment, and location in the study area. The area sources are

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treated collectively—by estimations of their daily uses of fuels, firing equipment, and location.

Fuel-use rates and therefore emission rates of air pollutants vary by season; this survey method provides a basis for determining the quantities of pollutants released at different times during the year. The general pattern of the seasonal variation in the total fuel use in an urban area, illustrated in Figure 5, allows the following assumptions:

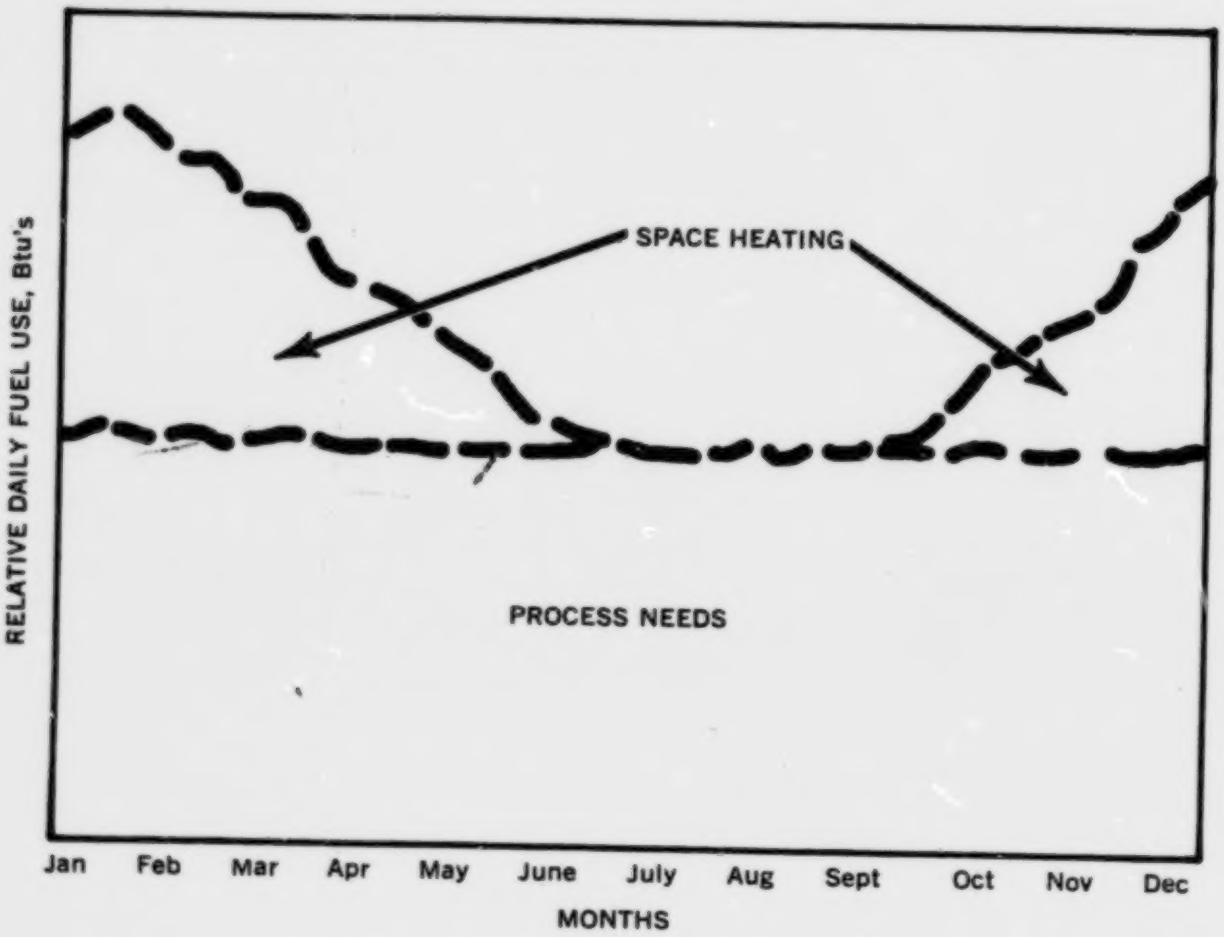


Figure 5 — Seasonal variation in fuel use rates.

1. A certain quantity of fuel is burned at a relatively uniform daily rate throughout the year. This fuel is used to provide energy for industrial processes, to generate power for steam-electric utilities, and to supply heat for cooking and water heating in households and commercial establishments. All of these fuel uses are relatively independent of the ambient temperature. Although these process uses vary from day to day and from hour to hour, these variations are assumed to be minor when compared to seasonal variations. The process daily fuel-use rates are considered uniform and are assumed to equal 1/365 of the fuel used for these purposes annually.
2. The remaining fuel use is markedly seasonal. The fuel is used to satisfy space-heating requirements of industries, households, institutions, and commercial concerns. This usage varies from a minimum of zero in summer to a maximum on

the coldest day of the year. The rate of fuel consumption for space heating is closely related to the degree-day value (see "Determination of Daily Fuel Use Rates") and is assumed to be proportional to the degree-day value.

Therefore, for each of the user categories, two distinct rates of fuel consumption are considered, i.e., uniform rate for processes and variable rate for space heating. By subdividing annual fuel-use into these two fractions, one can estimate the daily fuel consumption at specified times during the year.

Up to this point, fuel consumption in the study area has been subdivided first by type of user, then by type of source (point and area), and finally by type of use — for process needs and space heating. The next step is to determine the geographical distribution of fuel use within the study area. Since the locations of all point sources can be determined precisely, the fuels burned by each of these sources can be assigned to their exact locations. Methods for allocating fuel consumption by area sources to reporting zones are less exact. Domestic fuel use is distributed according to population density, commercial fuel use according to service employment, and manufacturing use on the basis of industry type and employment.

Detailed descriptions of the procedure just outlined, including sources of information, are presented in the following sections.

FUEL-USE INVENTORY

For purposes of this survey technique, the following annual fuel consumption data are required:

a. Total annual consumption of each fuel.

b. Annual consumption of each fuel by user category.

c. Annual fuel use by each point source.

d. Annual fuel use by area sources.

The sources of data given in the following paragraphs were chosen to provide these data quickly and with a minimum of field investigation. If fuel-use data for the study area are not directly available, an estimate based on the available information is sufficient. Such estimates may be necessary, for example, if the boundaries of the study area do not coincide with or include the service boundaries of utility companies or fuel distributors. Data available from the U.S. Bureau of Census publications or from national fuel associations are generally based on city, county, or metropolitan area boundaries, which again may not coincide with those of the study area.

Total Annual Fuel Consumption

The primary sources of information on the area's total annual consumption of individual fuels are the local utility companies for gas usage, National Coal Association for coal consumption, and State

Petroleum Marketers Association for fuel oil consumption. Additional sources of data for coal and fuel oil are the large local distributors of these fuels and operators of transportation facilities (railroads, barge lines, trucking firms). If any of the fuels are subjected to a special tax, data on fuel sales may be available from the tax division of local or state governments. Since any later assumptions with respect to portions of the fuel usage will be based on the total consumption figure, values for the total annual usage of each significant fuel should be obtained with the greatest possible accuracy.

Annual Consumption by User Category

1. *Manufacturing:* Annual fuel consumption by manufacturing industries is given in the Census of Manufactures publication MC63(1)—7, "Fuels and Electric Energy Consumed in Manufacturing Industries," available from the Government Printing Office, Washington, D.C. Latest issue is for year 1962. Data are given only for the 68 standard metropolitan statistical areas with manufacturing employment of over 40,000. For cities and metropolitan areas not included in this publication, the manufacturing fuel use must be estimated on basis of data from fuel distributors.

2. *Steam-Electric Utilities:* Annual fuel consumption by individual utility companies is published yearly in the National Coal Association publication, "Steam-Electric Plant Factors."

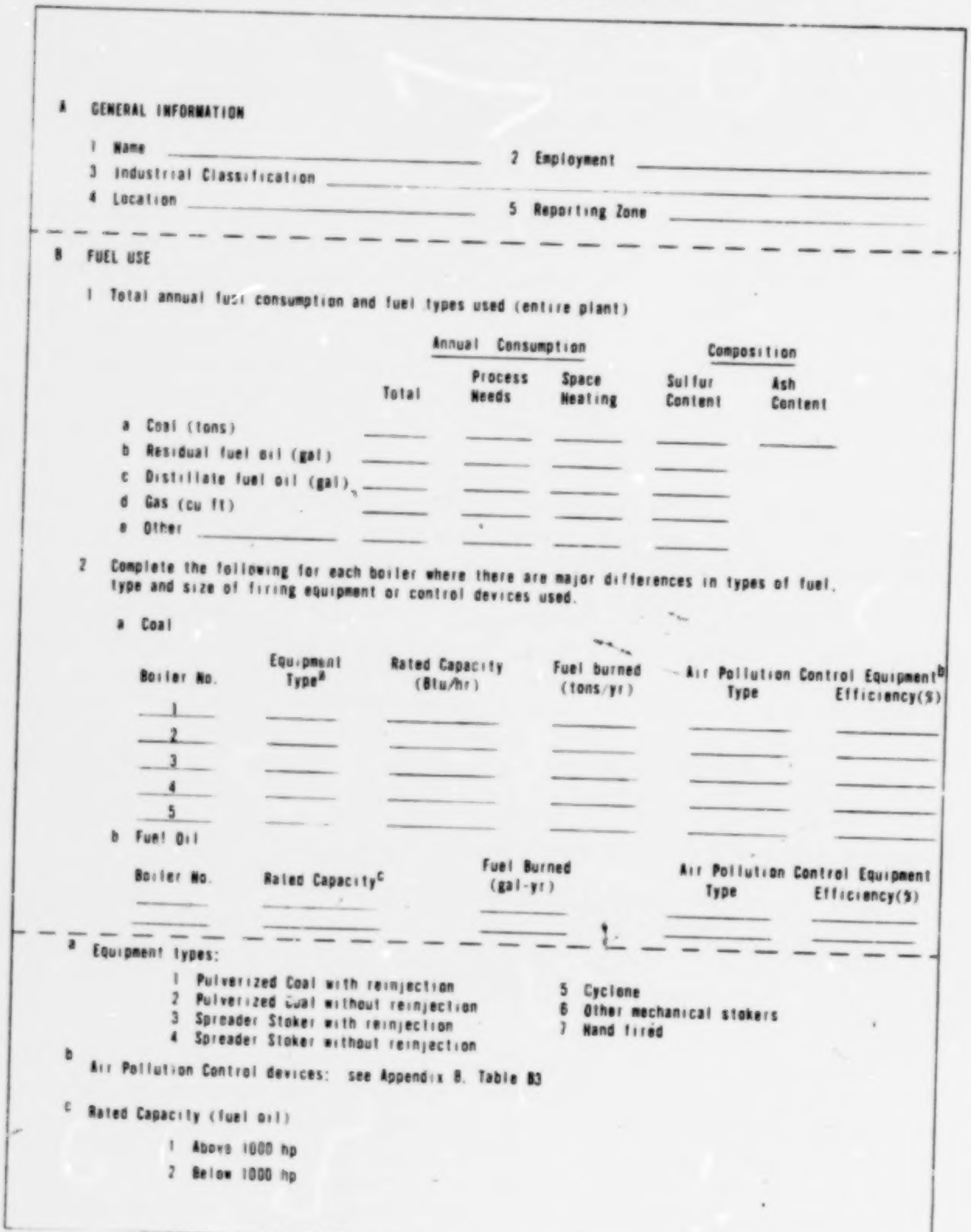
3. *Domestic, Institutional, and Commercial:* The annual consumption of fuels by domestic, institutional, and commercial users collectively may be obtained by subtracting manufacturing and steam-electric utility fuel use from the total consumption of each individual type of fuel. This quantity will be checked against other information and divided among the three subgroups by methods described in a later section.

Annual Consumption by Point Sources

The individual point sources in each of the user categories are now delineated. If the suggested criterion for point sources is applied (2 percent or more of a given fuel), the number of plants so delineated will range from about 10 to 50, depending on the size of the community.

Generally, these point sources within a community or area are well known. The list of the commonly known sources can be checked or supplemented by consulting the employment data for industry groups, such as primary metals or chemicals, known to be large users of fuel, as given in directory of manufacturers. A directory of manufacturers is usually compiled and published by state or local chambers of commerce or government agencies, such as a department of labor and industry. Electric generating plants are usually point sources.

You can obtain consumption and other data from each point source by individual contact. The information required is illustrated in a suggested reporting form, Figure 6. Information such as the rated capacity of each boiler may be obtained during the visit. Although such information is not used in this emission survey it may be useful in later air pollution control activities.



A GENERAL INFORMATION

1 Name ____ 2 Employment ____
3 Industrial Classification ____
4 Location ____ 5 Reporting Zone ____

B FUEL USE

1 Total annual fuel consumption and fuel types used (entire plant)

	Annual Consumption			Composition	
	Total	Process Needs	Space Heating	Sulfur Content	Ash Content
a Coal (tons)					
b Residual fuel oil (gal)					
c Distillate fuel oil (gal)					
d Gas (cu ft)					
e Other ____					

2 Complete the following for each boiler where there are major differences in types of fuel, type and size of firing equipment or control devices used.

a Coal

Boiler No.	Equipment Type[a]	Rated Capacity (Btu/hr)	Fuel burned (tons/yr)	Air Pollution Control Equipment[b] Type	Air Pollution Control Equipment[b] Efficiency(%)
1					
2					
3					
4					
5					

b Fuel Oil

Boiler No.	Rated Capacity[c]	Fuel Burned (gal-yr)	Air Pollution Control Equipment Type	Air Pollution Control Equipment Efficiency(%)

[a] Equipment types:
1 Pulverized Coal with reinjection
2 Pulverized Coal without reinjection
3 Spreader Stoker with reinjection
4 Spreader Stoker without reinjection
5 Cyclone
6 Other mechanical stokers
7 Hand fired

[b] Air Pollution Control devices: see Appendix B, Table B3

[c] Rated Capacity (fuel oil)
1 Above 1000 hp
2 Below 1000 hp

Figure 6 — Fuel use — point sources.

Annual Consumption by Area Sources

The annual consumption of each fuel in each user category is divided into two source subgroups—point sources and area sources.

It therefore follows that the difference between the annual consumption of fuel by a given user category and that consumed by the point sources under the respective user category, is the annual fuel use by area sources in that category. For example, if the annual usage of coal by the manufacturing category is 1,000,000 tons and three large manufacturing concerns or point sources collectively use 800,000 tons per year, the annual consumption by manufacturing area sources is 200,000 tons per year. To facilitate the succeeding steps, the results of the fuel use inventory may be summarized as shown in Figure 7.

A. USER CATEGORIES	COAL tons	RESIDUAL FUEL OIL gallons	DISTILLATE FUEL OIL gallons	GAS cu ft
TOTAL				
MANUFACTURING				
POINT SOURCES (TOTAL)				
AREA SOURCES				
STEAM-ELECTRIC UTILITIES				
POINT SOURCES				
AREA SOURCES				
DOMESTIC, INST., AND COMM.				
POINT SOURCES				
AREA SOURCES				
B. POINT SOURCES (by individual concerns)				
1.				
2.				
3.				
4.				
5.				

Figure 7 — Annual fuel use in the study area.

SUBDIVISION OF FUEL USE INTO PROCESS NEEDS AND SPACE-HEATING FRACTIONS

The data given in Figure 7, part A, represent the total annual consumption of fuels by the different source categories. To define the seasonal variation in fuel use, you must further subdivide fuel consumption into quantities of fuel used for space heating and for process needs.

Point Sources

The fuels consumed in point sources are subdivided into process-need and space-heating fractions on the basis of information from each of the point sources individually. If this information is not readily available, the relative usage should be estimated. This estimate can usually be obtained by using the difference between the firm's fuel use in summer and winter months as the space-heating fraction. All the fuels used by steam-electric utilities can be assumed to be in the process-need fraction of fuels, which are assumed to be used at a uniform daily rate, unchanged by seasonal variation.

Where large seasonal variations of the process fuel use by point sources are suspected, additional accuracy may be obtained by using the actual monthly fuel consumption data for both process and space heating.

Area Sources

1. *Manufacturing:* A substantial portion of the total manufacturing fuel use is generally centered in point sources. The quantities of fuels used for space heating and process needs by manufacturing category point sources have been defined. The remaining fuel use by the area sources is assumed to be subdivided in a similar manner. For example, if the total manufacturing coal usage is 1,000,000 tons and the sum of coal usage by manufacturing point sources is 800,000 tons with 600,000 tons used for process needs and 200,000 tons for space heating, the remaining 200,000 tons burned by manufacturing area sources may then be estimated as follows:

$$200{,}000 \text{ tons } \times \frac{600{,}000}{800{,}000} = 150{,}000 \text{ tons used for process needs by area sources}$$

$$200{,}000 \text{ tons} - 150{,}000 \text{ tons} = 50{,}000 \text{ tons used for space heating by area sources}$$

Although this assumption can introduce an error, the resulting error in a given zone will be minimal. The error is minimized because the assumption relates to the smaller portion of the fuel use and the resultant weights are distributed over a number of zones and averaged over a number of days.

2. *Domestic, Institutional and Commercial:* The total fuel consumption by this user category consists of a relatively constant "process" fuel use for water heating and cooking, and a seasonal fuel use for space heating. Generally, one can subdivide gas consumption into space heating and nonspace heating fractions fairly easily on the basis of information available from the local utility company. Since subdividing the other fuels into these components is more difficult and cannot be done in a similar manner, you should first consider the

domestic, commercial, and institutional fuel uses individually. In this way you can estimate the relative uses of fuels for process needs and space heating by this source category.

Domestic: Fuels are used in households for space heating, water heating, and cooking. The relative importance of each fuel for each of these purposes is shown in the U.S. Census of Housing publication HC(1), which presents the number of households utilizing each fuel. In communities where the use of coal and fuel oil for cooking and water heating is relatively minor (less than 10 percent), such use may be considered negligible. If the use of fuel oil and coal for these purposes is considerable, you can estimate the annual consumption by multiplying the number of households using a given fuel by the average use of fuel per household. The average annual use of, say, fuel oil for water heating and cooking per household may be obtained from the local fuel oil distributors or by using an amount equivalent to the gas usage per household for these purposes. The annual fuel consumption for domestic space heating may be estimated by the use of an empirical formula using degree days, number of households using a fuel, and an average fuel requirement per household per degree day. The use of this formula is explained in Appendix C.

Institutional: Total or individual usage in local public buildings and public schools can be obtained easily and rapidly from the appropriate local agency. The fuel usage is almost entirely for space heating. Individual private institutions such as hospitals and colleges should be treated as indicated below for the commercial category unless an individual facility is considered as a point source.

Commercial: It is difficult to estimate accurately the quantities of fuels burned by commercial users or to subdivide them into heating and nonheating fractions. For the purposes of this survey, the commercial fuel use is assumed to be entirely for space heating.

Information on commercial gas usage may be available from the gas utility. Where more accurate information is not available, the difference between total fuel usage and that assigned to other user categories may be assigned to this class. If reasonable care has been used in defining total fuel use and the previous subcategory uses, the introduced error will be relatively small.

DETERMINATION OF DAILY FUEL USE RATES

In the previous section, the total annual consumption of each fuel by user category was subdivided into two components—annual fuel consumption for processes and annual fuel consumption for processes and for space heating. Daily rates of fuel use, corresponding to the three conditions, i.e., minimum, average, and maximum space-heating-demand day, can now be determined. The fuel for processes was assumed to be used at a uniform daily rate, with the daily rate being equal to 1/365 of the annual fuel consumption. If many of the point sources in the study area shut down their operations on weekends, you may wish to substitute the number of working days for the 365 and to derive separate average weekday and weekend values.

The variation in the use of fuels for space heating can be defined on the basis of the degree-day value.* The degree-day data required for calculating space-heating-demand rates are:

1. Number of days per year showing a degree-day value.
2. Total number of degree days per year.
3. The annual maximum degree-day value.

Degree-day data may be obtained from the U.S. Weather Bureau publication "Local Climatological Data." For representative results, consideration of at least the three most recent calendar years is suggested. The quantity of fuel burned for space heating corresponding to the three conditions can be determined in the following manner:

1. Minimum space-heating-demand day—The minimum degree-day value is zero and occurs during the summer months. The space-heating fuel use for this condition is zero, and only the process fuel use is considered.
2. Average space-heating-demand day—The annual fuel consumption for space heating divided by the number of days showing a degree-day value yields the rate of fuel consumption for space heating corresponding to the average degree day.
3. Maximum space-heating-demand day — The space-heating fuel use rate on the maximum-demand day may be determined by the relationship:

$$\frac{\text{Maximum degree-day value}}{\text{Total no. of degree days per year}} \times \begin{array}{c}\text{Annual space-heating}\\ \text{fuel use}\end{array}$$

Add the two rates of fuel use (uniform process usage and variable space-heating usage) to determine the total daily rate of fuel consumption. For example, from fuel use inventory of study area, the annual coal consumption by manufacturing area sources is given as:

150,000 tons for process needs
50,000 tons for space heating needs.

From meteorological data,

Number of days showing a degree-day value = 260
Total number of degree days per year = 6,000
Maximum degree-day value = 60

---

*A degree day is a unit representing one degree declination from a given point (65°F) in the mean ambient air temperature for one day. For example, if the average daily temperature is 50°F, the number of heating degrees for that day is: 65°F—50°F = 15. It is a standard unit, reported by the U.S. Weather Bureau.

Fuel consumption rates for the three conditions are:

$$\text{Minimum day:}\quad \frac{150{,}000}{365} + 0 = 410\ \frac{\text{tons}}{\text{day}}$$

$$\text{Average day:}\quad 410 + \frac{50{,}000}{260} = 410 + 190 = 600\ \frac{\text{tons}}{\text{day}}$$

$$\text{Maximum day:}\quad 410 + \frac{60}{6000}\,(50{,}000) = 410 + 500 = 910\ \frac{\text{tons}}{\text{day}}$$

Similar calculations are performed for each fuel by user category and each point source. The results can be presented in a table, as shown in Figure 8.

SOURCES	COAL, tons			RESID. FUEL OIL, gallons			DIST. FUEL OIL, gallons			GAS, cu. ft.		
	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG	MAX
A. AREA SOURCES												
1 Manufacturing												
2 Domestic												
3 Commercial												
4 Institutional												
B. POINT SOURCES												
1												
2												
3												
4												

Figure 8 — Daily fuel consumption rates for minimum, maximum, and average space-heating day.

DISTRIBUTION OF FUEL USE TO REPORTING ZONES

Point Sources

Because relatively few point sources are present in a community or an area, their exact locations within the study area can be determined readily. It then becomes a simple matter to assign fuel consumption, as indicated in Figure 5, and subsequently emission rates of pollutants from these sources to the reporting zones where they originate.

Area Sources

Although the exact locations of the individual area sources, whether manufacturing, domestic, commercial, or industrial, are not known, the geographical distribution of their aggregate fuel use can be estimated. The following procedures, although dependent on personal judgment, should yield adequate estimates of the geographic distribution of area fuel use in the community. A substantial portion of the total fuel use will have already been located in point sources. Other types of fuel users tend to clump together in residential, commercial, and industrial areas. Furthermore, obtainable information about the community will usually provide reasonable guidelines for the apportionment of the individual fuels among zones in a study area. For example, the residential areas that use mostly gas for space heating can usually be pointed out by the gas utility. These areas are often the newer residential areas of the community. Conversely, residential use of coal is often confined to the older areas. The results of the geographic distribution of fuel use can be compiled in a table similar to that shown in Figure 9. You need not repeat the calculations for all three conditions. A multiplication factor $\left(\frac{\text{Maximum or minimum daily fuel use}}{\text{average daily fuel use}}\right)$ can be applied later to the average-day emission rates to yield emissions corresponding to the minimum and maximum days. The following procedure is to be performed only for the fuel consumption corresponding to average space-heating day.

REPORTING ZONE	MANUFACTURING				DOMESTIC				COMMERCIAL				INSTITUTIONAL			
	COAL	RESID FUEL OIL	DIST FUEL OIL	GAS	COAL	RESID FUEL OIL	DIST FUEL OIL	GAS	COAL	RESID FUEL OIL	DIST FUEL OIL	GAS	COAL	RESID FUEL OIL	DIST FUEL OIL	GAS
1																
2																
3																
4																
5																
6																
7																
8																
9																
.																
.																
.																
TOTALS[b]																

[a] Corresponding to average space-heating day.

[b] The totals should agree with those in Figure 5.

Figure 9 — Daily fuel consumption rates by reporting zones.

1. *Manufacturing Area Sources:* Note the reporting zones within the study area that contain concentrations of manufacturing industry.

Since only major centers of industrial activity, rather than individual small plants, are to be considered, the number of reporting zones so selected will generally be small. Aerial photographs, zoning maps, land-use maps, geodetic maps, and the Directory of Manufacturers are most helpful for this purpose.

Estimate the employment by industrial classification (Bureau of Census) in each reporting zone. The classification system used by the Bureau of Census is given in Appendix D. The reporting zone and employment size of each manufacturing concern can be obtained from the Directory of Manufacturers. Do not include the employment of concerns considered as point sources. The information may take the following form:

Chemical Industry

Total employment	=	2,000
X Company (point source)	=	1,200
Employment in area sources	=	800

Employment by zones:

zone a	=	500	62%
zone b	=	250	31%
zone d	=	50	7%

Allocation of manufacturing fuel use to reporting zones depends on the available information. If the study area is covered in the U.S. Census of Manufacturers publication, "Fuels and Electric Energy Consumed in Manufacturing Industry," and a breakdown of fuel use by industrial classification is given, then you may allocate fuel use in accordance with the percentage of employment in each zone as indicated in the foregoing example. If the study area is not covered in this publication or if the fuel-use data for the desired industrial groups have been withheld, the allocation of fuel use to reporting zones is more difficult. In these cases industrial fuel use can be allocated to zones by distributing coal and residual fuel oil to zones of heavier industry and distillate fuel oil and gas to zones of lighter industry. Land-use maps and inspection or permit data from various local agencies will be helpful.

If a city is large and complex, its manufacturing fuel use is usually described fairly well in the references already cited. In the smaller, less complex communities, for which reference material may be lacking, the personal knowledge of various city inspectors often can provide a reasonable basis for apportioning the fuels to the zones, particularly since some information will be available on employment by various industry classes in each zone.

2. *Domestic, Institutional, and Commercial Area Sources:* The following procedures may be used to distribute domestic, institutional, and commercial fuel usages.

Domestic (including apartment houses): Two procedures are given for distributing domestic fuel use to reporting zones. The first is based on census tract data, which present the number of dwelling units in each tract using a given fuel for space heating. These data have been compiled for 30 metropolitan areas listed in Appendix E. Upon request, the U.S. Bureau of Census can supply similar data for other areas at a price of several hundred dollars. With these data, the procedure for distributing fuel use is simple and accurate. Fuel use is distributed in proportion to the number of dwelling units using a given fuel in each reporting zone.

In the absence of census tract data, the following procedure is suggested:

- Determine the residential population of each zone. A breakdown of residential populations by census tracts for 180 tracted cities and metropolitan areas in the United States is available in the U.S. Bureau of Census publication PHC(1) "Census Tracts." These publications can be obtained from most libraries or from the Government Printing Office in Washington. You can then calculate the residential population of each reporting zone by summing the populations of census tracts within a given reporting zone. A breakdown of residential population can also be obtained from population density maps, which may be available from a local planning agency.
- Determine the number of dwelling units in the study area heated by each fuel. These data are given for the entire city instead of by census tract in the U.S. Census of Housing publication HC(1).
- Estimate the quantity of coal burned within each reporting zone.

    a. Select zones that use coal as a space-heating fuel. The use of coal is generally centered in older commercial and residential areas that are included in a relatively small number of reporting zones. Their general locations can usually be defined by various city inspectors and by the larger retail suppliers of domestic coal.

    b. Rank these zones according to their relative use of coal and estimate the percentage of the total number of dwelling units in the city using coal that are located in each zone. For example, the areal distribution of 10,000 dwelling units using coal (as reported in HC(1)) might be apportioned on the basis of judgment as follows:

    Zone a — 50% or 5000 units
    Zone e — 25% or 2500 units
    Zone f — 20% or 2000 units
    Zone x — 5% or 500 units

The local heating and ventilating, building, and fire departments, as well as retail coal dealers may be of assistance for these estimates.

c. Calculate the rate of coal consumption of each zone in accordance with the percentages above and the previously calculated daily coal consumption (Figure 5).

d. Determine the population in each zone using coal for heat. This can be done simply by multiplying the average number of inhabitants per unit (from Census of Housing) by the estimated number of dwelling units using coal. This population figure will be used to estimate the quantities of fuels burned in each reporting zone.

- Estimate the quantity of distillate fuel oil (grade no. 2) burned within each reporting zone in a similar manner. Although some residual fuel oil may be used in larger apartment houses, this use is usually minor and is ignored in this analysis. Such use of residual oil is generally reported in the proper zone in any event, since these apartment houses are usually in commercial zones where residual fuel oil is considered.

- Estimate the quantity of gas burned within each reporting zone:

a. Determine the population of each zone that is not satisfied by coal and fuel oil.

b. Distribute gas consumption to zones in proportion to this population.

NOTE: Often specific information on the distribution of domestic gas usage may be obtained from the local gas utility. If this is possible, it is preferable to obtain the fuel oil or coal distribution by difference.

Institutional: The fuels used by institutions may be distributed to reporting zones on the basis of school enrollment of each zone. The school population of each reporting zone may then be calculated by adding the enrollment of all schools located within the reporting zones. This information may be obtained from the local school boards. Although hospitals and public buildings are usually considered institutional, their fuel use can generally be distributed more accurately by the method indicated for the commercial category.

Commercial: Distribute the commercial fuel in a manner similar to domestic fuel use, but use service employment instead of the residential population as the basis for apportionment.

An estimate of the total employment by service industries in the study area may be obtained from the U.S. Bureau of Census publication PC(1) "General Social and Economic Characteristics." Service employment may be determined by reporting zones in the following manner.

- Estimate the employment of the central business district and other areas of high commercial activity. Generally, the central business district employs 40 to 50 perecnt of the total service employment. These data may be available from the local planning agency, traffic control agencies, or the chamber of commerce.
- Distribute the remaining service employment to the reporting zones in the same proportion as the residential population.

Alternative Distribution Procedure: If the fuel use by domestic, institutional, and commercial sources cannot be categorized by the procedures given, you may apply a procedure similar to that outlined for distributing domestic fuels and obtain a distribution for all three categories. In doing this, you would substitute equivalent population for residential population. Equivalent population of a reporting zone is the sum of residential, service employment, and school populations in that zone.

MOBILE COMBUSTION SOURCES

The mobile sources of air pollution include all vehicles that are propelled by the combustion of fuels. Automobiles, buses, trucks, locomotives, airplanes, and ships are the most common. Generally, emissions of pollutants from locomotives, airplanes, and ships, although significant locally, do not add considerably to the community-wide air pollution; for the purposes of a gross and rapid appraisal of emission rates these sources are not considered. Emission rates of pollutants from mobile combustion sources are then estimated on the basis of gasoline and diesel fuel consumption in the area by automobiles, buses, and trucks.

Total gasoline consumption in an area can be more easily and accurately defined than consumption of diesel fuel. By assuming that the gasoline consumption is roughly equal to the gasoline sales in an area, you may use gasoline sales data as the basis for determining the emission rates of pollutants. This is not the case for diesel fuel. The prime users of diesel fuel are the long-haul trucks that may purchase the fuel in the study area but use most of it outside the area. Since the diesel vehicles comprise only a small fraction (less than 2%) of the total traffic in a community, a rough estimate of diesel fuel consumption is usually sufficient. Use of diesel fuel by buses of the local transportation company can usually be obtained accurately.

An index of the geographical distribution of the mobile fuel use within a community is the distributional patterns of traffic volumes or counts. In many communities traffic-flow maps have been developed on the basis of traffic counts. Such flow maps are used to compute the total vehicle-mileage traveled in a zone. Gasoline and diesel fuel consumption can be allocated on a vehicle-mile basis to the sub-areas or reporting zones.

The traffic counts and thus the emission rates of pollutants exhibit daily and seasonal variations. For the purposes of this survey method, daily variations in traffic are not considered and the average daily consumption of fuel is assumed to equal 1/365 of the annual. As indicated for point sources, these estimates may be refined to consider average weekdays and weekends. The effect of seasonal variations can also be accounted for. For summer use of gasoline, increase the emission rates of pollutants for the average day by a ratio of the average summer-day traffic to the yearly average (approximately 1.09); for the winter use of gasoline, decrease the average-day emission rates by the ratio of average winter-day traffic to the yearly average (approximately 0.92).

GASOLINE CONSUMPTION

Three basic items of information are needed for estimating the gasoline consumption in reporting zones:

1. Total annual sales of gasoline in the study area.
2. Traffic-flow maps, indicating the traffic counts by segments of the major thoroughfares.
3. Estimate of the seasonal variation in traffic counts.

The sources of these data and the methods of applying them to estimate gasoline consumption are given in the following paragraphs.

1. *Total Annual Gasoline Sales*

Gasoline sales data for the city or county may be available from the State Petroleum Marketers Association. If it is not, you can obtain an adequate estimate from data in the American Petroleum Institute publication "Petroleum Facts and Figures" and the U.S. Bureau of Census publication "Retail Trade." Gasoline consumption by state is given in "Petroleum Facts and Figures," whereas gasoline service-station sales in dollars is given by cities, counties, and states in the U.S. Bureau of Census publication. Since service-station sales include other items, such as motor oil, batteries, and tires, these records cannot be used directly to determine the gallonage sold. Assuming that the ratio of gasoline sales to total service-station sales is comparatively constant within a state, you may use the following ratio to estimate the gasoline sales in the study area.

Gasoline sales in study area (gal) =

$$\frac{\text{Service-station sales in study area (\$)}}{\text{Service-station sales in state (\$)}} \times \text{gas sales in state (gal)}$$

Various checks can be applied to this estimate. Vehicle registration multiplied by average vehicle mileage per auto per year can be combined with average miles per gallon to obtain an estimate of yearly gasoline consumption. This information is available through references such as "Automobile Facts and Figures" and "Petroleum Facts and Figures" for the most recent year.

2. *Traffic-Flow Maps*

The traffic-flow maps present the average daily traffic volumes by segments of the major thoroughfares in the community. Although, the so-called "major" thoroughfares comprise only a fraction (20-30%) of the total street mileage in a community, they carry the major load of the vehicular traffic. By assuming that the vehicle-mileage traveled on secondary streets in a zone is proportional to the vehicle-mileage traveled on the major thoroughfares, one may use the traffic-flow maps as the basis for distributing total gasoline consumption. The traffic-flow maps or estimates are available from the local traffic control or planning agencies.

3. *Estimates*

Estimates of seasonal and daily variation in traffic counts may be obtained from the local traffic control agency.

The mechanics for calculating gasoline usage in each reporting zone are illustrated in a sample form, Figure 10.

DIESEL FUEL CONSUMPTION

The principal users of diesel fuel are buses and trucks. Generally, data on fuel consumption by buses are readily available from the local transit company. These data, coupled with information on location of bus routes, number of buses, and vehicle-mileage, may be used to estimate the relative usage of diesel fuel in each reporting zone by a procedure similar to that used for the distribution of gasoline usage.

Diesel fuel consumption by trucks traveling in the study area may be estimated roughly by the following procedure:

1. Estimate the vehicle miles (in % of total) traveled by diesel-powered vehicles in the study area. The local traffic control agency, state highway department, or state and national trucking association may be helpful.
2. Calculate the diesel fuel consumption by multiplying the vehicle-mileage by 5.1 miles/gallon.[2]
3. Distribute the fuel consumption to reporting zones by assuming the same distribution as for gasoline.

REFUSE COMBUSTION SOURCES

Incineration, open burning, and sanitary landfills are the principal methods of refuse disposal in urban areas. The burning of refuse may constitute a significant source of community air pollution, par-

GPO 828-519-3

(1) REPORTING ZONE	(2) VEHICLE MILES PER DAY	(3) % VEHICLE MILES	(4) GASOLINE CONSUMPTION
1			
2			
3			
.			
.			
.			

Column 1: Reporting zone number

Column 2: Daily vehicle mileage. Multiply indicated traffic counts by the distance traveled in each zone. The distances can be scaled from the traffic-flow map. Delineation of reporting zones on the traffic-flow map will be helpful.

Column 3: Percentage of vehicle miles. Divide the vehicle-mileage of each zone by the sum of column 2 and multiply by 100.

Column 4. Daily fuel usage in each zone. Multiply % of total vehicle miles (column 3) by the average daily gasoline consumption of the study area. The average daily rate of gasoline consumption is assumed as 1/365 of the annual.

Figure 10 — Daily consumption of gasoline by reporting zones.

ticularly where burning is done in the open or incineration is poor. The quantities of pollutants released may be estimated on the basis of type of burning and the quantity of refuse material burned.

The total amount of refuse produced in a community may be estimated. This refuse is disposed of through municipal or private collection, with disposal at some relatively large collective site; or it remains uncollected, with disposal at the point of origin, i.e., the individual home, store, or plant. Information can generally be obtained on the daily tonnage of refuse disposed of at the collective sites. If the method of disposal leads to significant air pollution, these sites are considered as point sources. The remaining refuse is apportioned as area source material to the various zones.

The rate of refuse disposal is assumed to be constant throughout the year. Actually, the rate of refuse production is somewhat higher than the annual average in the spring and summer.

TOTAL AREA ESTIMATE

Estimates of the total daily tonnage of refuse generated in the community are generally available from the city agency responsible for its disposal and from the private haulers. These estimates may or may not include all of the commercially and industrially generated refuse. A check figure can be calculated by using national per capita averages. Generally 4 pounds per capita total refuse and approximately 3 pounds per capita for combustible refuse will provide a gross estimate of refuse production. These averages include domestic, commercial, and industrial refuse.

DISPOSAL AT COLLECTIVE SITES

The quantity of refuse disposed of at specific collective sites, which include municipal or commercial incinerators, dumps, and landfills, may be obtained from the local refuse collection agencies. Although the quantity of refuse disposed of in sanitary landfills or hauled well outside the survey area for disposal are not considered as contributing to air pollution in the community, it is important to define these amounts for subsequent determination of area disposal. For the remaining tonnage the following information is needed.

Incinerators

The location, operating and design capacities, operating schedules, and efficiency of control equipment should be determined for each incinerator. This information may be obtained from the public or private refuse collection agencies or foremen of the individual installations. The data may be presented in a tabular form, showing the location (reporting zone) of each incinerator and the average daily tonnage burned.

Open Burning Dumps

The location of each dump, the burning schedule, and the estimated average daily tonnage need to be determined. The sources of information are the same as for incinerators.

DISPOSAL AT POINT OF ORIGIN

The difference between total area estimate and the quantity disposed at collective sites may be assumed to be the quantity of refuse burned at the point of origin by domestic incineration and backyard burning or by industrial-commercial burning of an equivalent type. For purposes of areal distribution and emission-rate calculations, this quantity must be further sub-divided into industrial-commercial disposal and domestic disposal. This division can be based on supplemental information such as burning regulations, data on issuance of burning permits, and the like. The result will be only a rough estimate. The quantity of refuse burned domestically can be distributed to reporting zones in proportion to residential population, whereas the commercial-industrial refuse is assigned to the commercial-industrial zones.

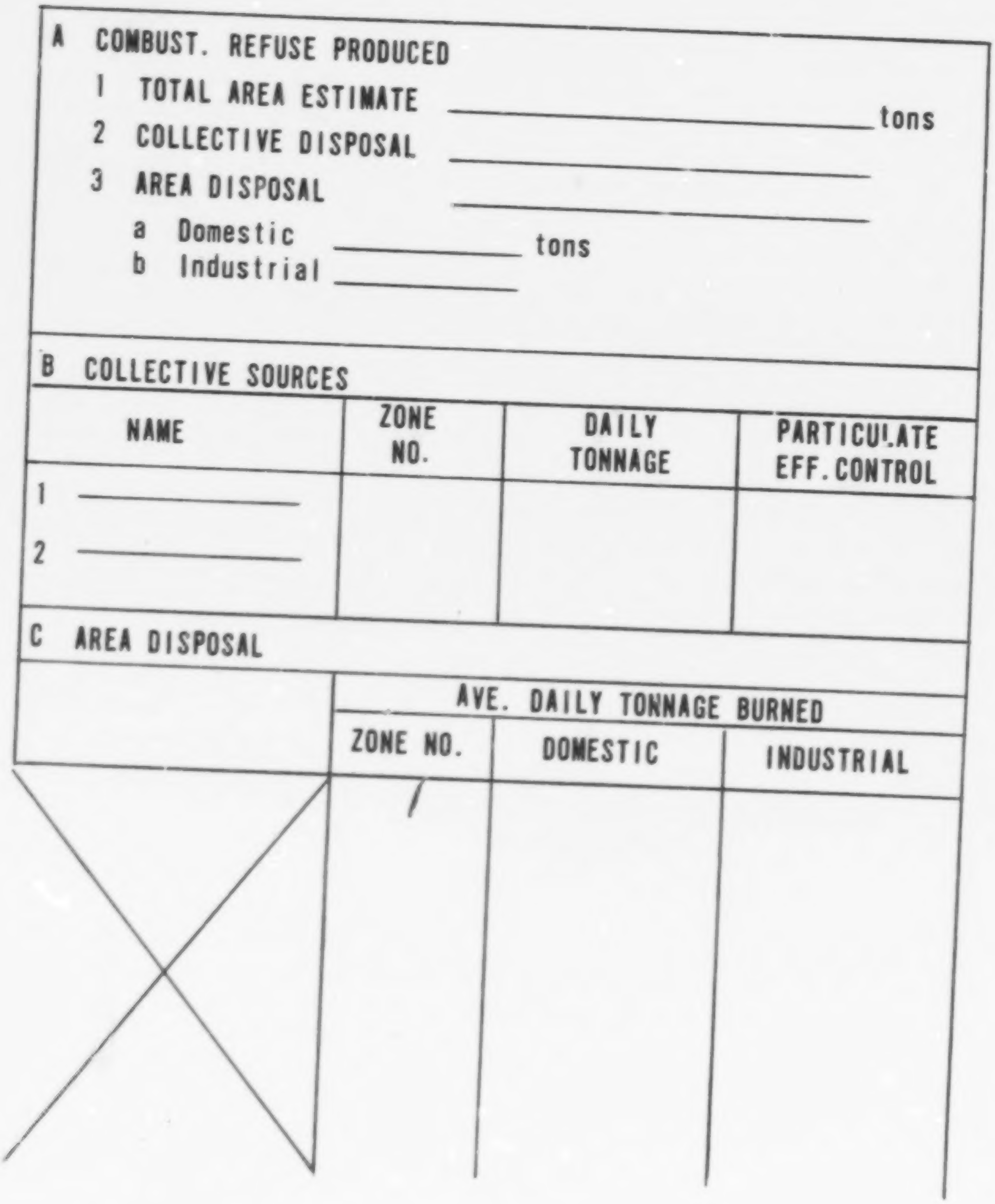
Usually the portion of the refuse ascribed to domestic or industrial-commercial is delineated by the collection patterns of the governmental or private refuse collection systems. Where good residential collection is made by the community or by contract with private haulers, the percent of the remaining refuse burned in backyards is small and most or essentially all of the refuse may be placed in the industrial-commercial class. In either case, the preferential use of incineration or open burning at the point of origin and the approximate degree of such use may be obtained from the agency responsible for refuse collection or from other agencies such as police and fire departments. Generally one can specifically account for well over 50 percent of the total overall tonnage of refuse and its method of disposal.

The data may be compiled in tabular form, as shown in Figure 11.

INDUSTRIAL PROCESS LOSS SOURCES

The quantities of the different contaminants discharged from most industrial and some commercial establishments are attributable to two general types of operations. First, the pollutants generated by the combustion of fuels for space heating and process needs, which were discussed in "Stationary Combustion Sources," and second, the pollutants generated by the industrial processes themselves. Estimation of emission rates of pollutants associated with the latter is discussed briefly in this section.

The lack of quantitative data concerning the emissions of pollutants due to industrial process losses and the diversity and multitude of these sources in a community present difficulties in making a rapid assessment of the pollution load from these sources. The processes may contribute to localized air pollution problems in the vicinity of an individual plant without significantly polluting the community's total air supply. A single spray-painting operation is an example of such a localized problem, since the operation may cause specific odor problems or property damage in its immediate vicinity without contributing a substantial amount of solvents or aerosols to the community's air; however, all the spray-painting operations collectively in the community may produce a significant amount of hydro-



A COMBUST. REFUSE PRODUCED

1 TOTAL AREA ESTIMATE ____________ tons

2 COLLECTIVE DISPOSAL ____________

3 AREA DISPOSAL ____________

a Domestic ________ tons

b Industrial ________

B COLLECTIVE SOURCES

NAME	ZONE NO.	DAILY TONNAGE	PARTICULATE EFF. CONTROL
1 ________			
2 ________			

C AREA DISPOSAL

	AVE. DAILY TONNAGE BURNED		
	ZONE NO.	DOMESTIC	INDUSTRIAL

Figure 11 — Refuse disposal.

carbons. Accurate definition of the portion of the total pollution resulting from many industrial processes requires considerable skill with respect to knowledge of both the processes and the test methods. Often the portion of the pollution so defined will be found to be minor when compared to that resulting from the combustion of fuels. A number of industrial processes should be examined, however, even in a rapid survey, because of their nature, the size of the individual plants, or the concentration of a type of industry in a given community.

INDUSTRIAL PROCESS LOSSES

Emission factors, related mostly to production data, have been developed for some of the industrial operations that may be important in a community survey:

1. Iron and steel mills
2. Ferrus and nonferrus foundries
3. Petroleum refineries
4. Asphalt batching plants
5. Coffee processing
6. Kraft pulp mills
7. Mineral acid production
    a. Sulfuric acid
    b. Nitric acid
    c. Phosphoric acid
8. Cement production
9. Concrete batching
10. Dry cleaning plant solvent emissions

Any other type of process that is suspected of importance on the basis of complaints or observations of emissions should also be examined.

Emission rates of pollutants from process losses may be estimated by considering the type of processes and materials used, the production volume, and the efficiency of air pollution control equipment of each industrial process individually; the appropriate emission factors given in the appendix are then applied. The procedure for selecting the important process sources in the study areas and the data required for emission-rate calculations are given below:

1. Note the name and location of the processes that are to be considered. This tabulation can be facilitated by the use of the Directory of Manufacturers, which lists the companies by industrial classification. Employment data given in this publication may be used to pinpoint the large sources.
2. Obtain production data (annual and average daily) and the efficiency of control equipment, if any, from each of the selected concerns.
3. Calculate the emission rates by applying emission factors to the production data.
4. Assign the average daily emission rates to the respective reporting zones.

Sometimes the total area loss from certain types of processes may be estimated with relative ease when compared to the difficulty of defining all of the individual sources. One example of such an estimate is that described for the loss of solvents from dry cleaning plants (see Appendix F). In this example the losses are based on derived per capita loss figures. The emissions would be proportioned among the commercial zones.

Solvent losses from printing and painting operations can be based on the assumption that all of the solvent is evaporated into the atmosphere. Estimates of the gallonage of inks or paints sold in the area can be obtained from major manufacturers of or users of these products. These sources of information and standard texts will indicate the usual percentages of solvents in the inks and paints. The solvent losses can be apportioned to the various commercial and industrial zones on the basis of commercial and industrial employment if more specific information on area of use is not available. Paint usage in residential areas is generally minor compared to the industrial usage. Where the volume of house paint sold in an area is known, its resultant solvent loss can be apportioned to the zones on the basis of residential population.

CALCULATION OF POLLUTANT EMISSIONS

Products of combustion are formed during the burning of the various fuels, gasoline, and refuse material, all of which have been compiled under subheadings. The nature and amounts of these products reaching the air as pollution depend on the quantity and type of material burned, the manner of burning, and the collection efficiency of any control devices used to clean the emissions before their discharge to the atmosphere. The types and quantities of the various materials burned have been segregated by location and general types of combustion processes in tables such as those shown in Figures 8 through 11. Now this information must be translated into estimates of pollution emissions. This is accomplished by applying appropriate emission factors to the various quantities of fuels and refuse burned. The units most commonly used to report emission rates are pounds or tons per day.

It is important to note that emission factors represent the average of a wide range of values. Although they may be used accurately to predict the total emissions from a large number of similar fuel users or processes, the application of these factors to an individual or comparatively small number of fuel users or industrial processes may result in a considerable discrepancy between the actual and calculated values. This discrepancy is minimized somewhat by considering each user category separately; however, the many design and operating variables present within a given user category are responsible for variations in the emission rates. The results, therefore, should be thought of as relative rather than as absolute emission rates.

In selecting the appropriate emission factors and calculating emission rates, one must consider the sulfur and ash contents of fuels, the type of burning method, and the degree of control employed.

SULFUR AND ASH CONTENT OF FUELS

Most of the sulfur in fuels is oxidized in the combustion process and is emitted to the air primarily as sulfur dioxide. The air used in the combustion process will pick up and carry a portion of the fuel out of the stack, usually in the form of particulate fly ash or carbon. The manner in which the fuel is burned will influence the amount of these particulates released to the atmosphere.

The sulfur content of coal can vary from less than 1.0 percent for some anthracite and medium-volatile bituminous coals to over 5 percent for some high-volatile bituminous coal. The ash content of coal ranges from approximately 3 to 18 percent, depending on the type.

The sulfur content of fuel oil depends on the grade of oil (Numbers 1 through 6) and also on the geographical area of origin. For example, the sulfur content of No. 2 fuel oil ranges from an average of 0.24 percent in the eastern United States to approximately 0.35

percent in the western regions. Sulfur content also varies with the grade of oil, ranging from 0.11 percent for No. 1 fuel oil to over 3 percent for No. 6 fuel oil. The distillate oils (generally No. 2) are usually used for domestic and light commercial space-heating purposes. The residual fuel oils (Nos. 5 and 6) are used almost entirely by major commercial and manufacturing firms and by electric-generating utilities. The other fuel oil grades are special-use fuels. Their use, in gallons, is substantially less than that of grades 2, 5, and 6.

The sulfur content of gas is almost negligible, but should be considered if gas is the principal fuel in the study area.

Point Sources

Since each point source is considered individually, the chemical composition of fuels burned at each source should be defined precisely through information from the user. If the specific information is not available, use the information sources listed for area sources.

Area Sources

Since precise determination of sulfur and ash contents for area sources would be time-consuming, the use of an average ash and sulfur content is suggested. You will need an average ash and sulfur content for coal, average sulfur content of distillate fuel oil (Numbers 1-4, but usually only No. 2), average sulfur content of residual fuel oil (Numbers 5 and 6), and sulfur content of gas. These data may be obtained from local distributors of these fuels and checked against the data published in *Mineral Yearbook-Fuels,* Bureau of Mines, for coal; and "Burner Fuel Oils Mineral Industry Survey," Bureau of Mines, for fuel oil.

TYPE OF BURNING

Although burning methods have been somewhat segregated by considering each user category independently, variations in firing equipment within a given user category can produce wide variations in emission rates of certain pollutants; these variations should be considered. For example, the release of particulates per unit of coal burned depends on the type of firing equipment. Similarly, the emission of pollutants per unit of fuel oil burned depends on the relative size of the combustion unit.

Point Sources

Since each point source is considered individually, the type of firing equipment has been defined and listed as indicated in Figure 6. With this information you can select the appropriate emission factor for each pollutant from Appendix F.

Area Sources

Following are guidelines for selecting appropriate emission factors for area sources.

1. *Combustion of Coal*

For particulate emissions from all area sources use the factor for "All other stokers" in Appendix F, Table F6. Factors for emissions of various gaseous pollutants are indicated in the appropriate tables in Appendix F by user category.

2. *Combustion of Fuel Oil*

All area sources may be assumed to be in the "less than the 1000 hp." category, for selection of emission factors from Table F10.

3. *Combustion of Gas*

See Table F9.

4. *Domestic Refuse Disposal*

Select the most widely used method of on-site domestic refuse disposal and apply the appropriate factor from Tables F17 and F18, to all on-site domestic refuse burning. Where better definition of the use of backyard burning or domestic incineration can be obtained from auxiliary sources of information, apply the specific factors to each portion of the refuse.

5. *Industrial and Commercial Refuse Disposal*

Table F17, lists emission factors for both single- and multiple-chamber incinerators. Since some of the refuse at these sites will also be open-burned, the intermediate factors for single-chamber incinerators may be used for this refuse, unless knowledge of the community laws and practices allows more definite selection of the factor.

DEGREE OF CONTROL

The emission factors given in Appendix F represent the emission rates of pollutants on the basis of no control. Releases of gaseous pollutants — sulfur dioxide, oxides of nitrogen, and hydrocarbons — are generally uncontrolled, except in certain process sources, and may be calculated directly. In addition to the gases, the emissions of particulates from mobile sources are also uncontrolled and may be calculated directly. Particulate emissions from some combustion sources and central refuse disposal incinerators are often reduced by the use of air pollution control devices. For a realistic picture of pollutant releases, any reductions of emissions through the use of control equipment should be considered.

Point Sources

The larger combustion sources that use coal — steam electric utilities and some manufacturing concerns — generally employ control devices to reduce the quantity of particulates released to the atmosphere. Many large refuse incinerators also use control devices. As indicated in Figure 6, the efficiency of such devices should be obtained for each point source. The emission rates of particulates will then equal

$$\begin{matrix}\text{Fuel used}\\ \text{or}\\ \text{Refuse burned}\end{matrix} \times \text{Emission factor} \times \frac{(100\% - \text{efficiency of collection})}{100}$$

The fuel used or refuse burned is designated in units of weight or volume consistent with the emission factors given in Appendix F.

In Appendix B, Table B3 presents average efficiencies for the various kinds of control equipment. These averages may be compared with information obtained from point sources or may be used when detailed information is unobtainable. Further information on air pollution control equipment may be found in texts such as "Air Pollution", edited by Arthur C. Stern, and "Air Pollution Handbook", edited by Paul L. Magill et al.; or general handbooks such as "Chemical Engineers' Handbook", edited by Robert H. Perry et al.

Area Sources

The smaller combustion sources or ones using lighter fuels are generally uncontrolled. For the purposes of this survey method, the emissions of all pollutants, including particulates, are calculated directly by assuming no control of area sources.

PRESENTATION OF RESULTS

This survey method will yield emission rates in tons per day of the various pollutants in sub-areas or zones. This information can then be presented in a number of ways. It can depict the relative contribution to the various pollutants by source categories (i.e., manufacturing sources, mobile sources) in a study area or a reporting zone. Tables or charts may be prepared to illustrate the buildup patterns of individual pollutants over an area. The results can be displayed in various ways that allow comparisons of percentages of the total of each pollutant resulting from each type of fuel use or by the category of use, such as coal versus residual oil, manufacturing versus domestic, or stationary versus mobile sources. If the effects of point sources versus area sources are of particular interest, the method of presentation should aid such comparisons. The format of reporting is dictated by the individual objectives. Remember that data should be formulated to show desired relationships, not just meaningless numbers.

Average, Maximum, and Minimum Day. Methods for calculating the average, maximum, and minimum daily emission rates, where applicable, have been given in earlier sections. Of the four user categories discussed, only two, combustion of fuels by stationary sources and mobile combustion sources are assumed to vary significantly throughout the year. Space-heating demand was assumed to be proportional to the degree-day value and thus varies from zero during the days of zero degree-day value to a maximum emission rate on the maximum degree day. Transportation emissions, proportional to traffic volume, are generally maximum during summer months and minimum during winter months. The other two source categories, process losses and refuse disposal, are assumed to maintain uniform operations and thus constant emissions throughout the year.

In adding the emissions from the different source categories, remember that during the maximum space-heating-demand day, the transportation emissions, based on seasonal variation, are generally minimum, and vice versa. For example, the emission rate during the maximum space-heating-demand day will equal the sum of maximum stationary combustion source emission, minimum transportation emission, process losses, and refuse disposal emissions.

Emission Maps. For each pollutant, the emission rates in tons per square mile can be presented effectively on a reporting zone map. This can best be accomplished by categorizing the zones according to emission rates and then depicting variations of zonal emissions by the use of colors, shading, or symbols. Such a presentation will show areas of relatively high, moderate, and light emission rates of each pollutant. The influence of point sources may be shown by presenting two sets of maps for each pollutant — one including and the other omitting emissions from point sources. A few suggested formats for presenting emission inventory data are given in Figures 1, 2, and 12.

EMISSION RATES (TONS/DAY)
TOTAL STUDY AREA

SOURCE CATEGORY	MAX. SPACE HEATING DAY				AVE. SPACE HEATING DAY				MIN. SPACE HEATING DAY			
	SO_2	NO_x	HC	Part.	SO_2	NO_x	HC	Part.	SO_2	NO_x	HC	Part.
STATIONARY COMBUSTION												
1 Manufacturing												
2 Steam Electric Util.												
3 Domestic & Commercial												
MOBILE SOURCES												
REFUSE DISPOSAL												
INDUSTRIAL PROCESS LOSSES												
TOTALS												

EMISSION DENSITY (TONS/Sq. MILE/DAY)
BY REPORTING ZONES

ZONE NO.	MAX. SPACE HEATING DAY				AVE. SPACE HEATING DAY				MIN. SPACE HEATING DAY			
	SO_2	NO_x	HC	Part.	SO_2	NO_x	HC	Part.	SO_2	NO_x	HC	Part.

EMISSION RATES (TONS/DAY)
POINT SOURCES

ZONE NO.	POINT SOURCE				
		SO_2	NO_x	HC	Part.

Figure 12 — Examples of summary tables.

Such tables and maps are only a few of the various methods by which these data may be presented. Emission inventory data may be interpreted more easily if additional information is included. Such supplementary information as physical description of the study area, meterological summary, discussion of industries (existing and anticipated), and population projection may be included.

APPENDIXES

A. Reference Guide

B. Conversion Factors

C. A Method for Calculating Domestic Fuel Use from U.S. Bureau of Census Data

D. Standard Industrial Classifications (SIC)

E. Metropolitan Areas — Fuel Use Data

F. Emission Factors

APPENDIX A. REFERENCE GUIDE

Data items	Sources of information
Metropolition area map Population density map Land-use map Zoning map Aerial photographs	Metropolitan area or city planning commissions
Sanborn maps	Local insurance companies
Census tracts	U. S. Bureau of Census "PHC (1) — Census tracts"[a]
Annual gas consumption	Local gas utility company
Annual coal consumption	National Coal Association[b] Local distributors of coal Transportation facilities
Annual fuel oil consumption	State Petroleum Marketers Assoc. Local distributors of fuel oil
Manufacturing fuel use	U. S. Bureau of Census Census of Manufacturers, "Fuels and Electric Energy Consumed in Manufacturing Industries"[1]
Steam-electric utilities fuel use	National Coal Association "Steam Electric Plant Factors"[b]
Names and locations of point sources	Director of Manufacturers, Local Chamber of Commerce
Annual fuel use by individual point sources; quantities used for heating and process use	Each individual point source
Domestic fuel use—number of households	U. S. Bureau of Census, Census of Housing, "HC(1)"[a]
Per dwelling unit use of fuels	Local distributors of fuels
Institutional fuel consumption	Local government agencies Board of Education
Meteorological data (degree days)	U. S. Weather Bureau, "Local Climatological Data"
Geographic location of industries	Aerial photographs Land-use maps Directory of Manufacturers Local building and fire departments

Geographic distribution of domestic fuel use	Land-use maps U. S. Bureau of Census, "Census of Housing, HC(1)" "Number of Heating Units by Census Tracts" "PHC(1)—Census Tracts"[a] Local gas utility company Local distributors of fuels
Geographic distribution of institutional fuel use	Local Board of Education Land-use maps
Geographic distribution of commercial fuel use	Land-use maps U. S. Bureau of Census, "PC-C General Economic and Social Characteristics"[a] Local planning agency
Total annual gasoline sales	"Petroleum Facts and Figures"[c] U. S. Bureau of Census, Census of Business, "Retail Trade"[a]
Geographic distribution of traffic	Traffic-flow maps
Seasonal distribution of traffic	Local traffic control agency
Diesel fuel consumption	Local traffic control agency National Trucking Association Local transit companies
Total area estimate of refuse production	Local sanitation agency Private haulers of refuse
Refuse disposed at collective sites	Local sanitation agency Incinerator and dump operators
Location of industries	Directory of Manufacturers
Production data	Individual industries
Chemical composition of fuels	"Mineral Year Book—Fuels" "Burner Fuel Oils—Mineral Industry Surveys"[d]

[a] Superintendent of Documents
Government Printing Office
Washington 25, D. C.

[b] National Coal Association
1130 Seventeenth St., N. W.
Washington 25, D. C.

[c] American Petroleum Institute
1271 Avenue of the Americas
New York 20, New York

[d] U. S. Department of Interior
Bureau of Mines
Washington 25, D. C.

GPO 828-519-4

APPENDIX B. CONVERSION FACTORS

TABLE B1. THERMAL CONVERSION FACTORS FOR COMPETITIVE FUELS

Solid Fuels	*Btu (Gross)*
Bituminous coal and lignite	26,200,000/net ton
Anthracite (Pennsylvania)	25,400,000/net ton
Briquets and packaged fuels	23,000,000/net ton
Wood including mill wastes	20,960,000/cord
Liquid Fuels	
Crude (U.S.) oil	5.8×10^6/bbl
Distillate fuel oils (Grades 1-4)	5.8×10^6/bbl
Residual fuel oils (Grades 5-6)	6.3×10^6/bbl
Gaseous Fuels	
Natural gas, wet	1,075/cu ft
Natural gas, dry	1,050/cu ft
Manufactured gas	550/cu ft

TABLE B2. GENERAL CONVERSION FACTORS

Weights and Volumes of Petroleum Products

1 Barrel = 42 gallons

Fuel	Pounds per Gallon	Pounds per Barrel	Barrels per Ton
Crude (U.S.)	7.08	297	6.73
Gasoline	6.17	259	7.72
Distilled oil	7.05	296	6.76
Residual oil	7.88	331	6.04
Asphalt	8.57	364	5.50

Gas

1 therm	100,000 BTU	95 cu ft

TABLE B3. EXPECTED EFFICIENCY OF PARTICULATE CONTROL EQUIPMENT

Type of Collection	Estimated Efficiency, %
Settling	30
Cyclone	80
Electrostatic precipitation	80
Wet scrubbing	85
Mechanical—electrostatic combination	95
Fabric filters	99

APPENDIX C. A METHOD FOR CALCULATING DOMESTIC FUEL USE FROM U. S. BUREAU OF CENSUS DATA

Technical Assistance Branch
Division of Air Pollution

A comprehensive census of the U. S. population is made every 10 years. As part of this census, the characteristics and numbers of dwelling units in various political subdivisions are determined (Census of Housing). One item recorded in the Census of Housing is the number of dwelling units heated with the various types of fuels. Converting this information into domestic fuel use for a given area is usually required for an inventory of air pollution emissions. A method of doing this is briefly outlined.

Basic assumptions and data are:

1. Average energy use for space heating in this country is 70×10^6 Btu/year-household.[1]
2. Average number of annual heating degree days* for the country is 4600 (rounded).[1]
3. Average size of household: 4.9 rooms/dwelling unit. Use 5 rooms/dwelling unit.[2]
4. Assumed fossil fuel characteristics

Fuel	*Heating value*	*Combustion efficiency*
Coal	26×10^6 Btu/ton	50%
Oil	145,000 Btu/gallon	60%
Gas	1,000 Btu/cu ft	75%

Derived data:

5. Heating requirements per household

$$\frac{70 \times 10^6 \text{ net Btu/year-household}}{4600 \text{ degree days/year}} = \text{15,200 net Btu/household-degree day}$$

6. Fuel requirements per household

(a) Coal

$$\frac{\text{15,200 Btu/household-degree day}}{(0.50)\ 26 \times 10^6 \text{ Btu/ton coal}} = \text{0.0012 ton coal/household-degree day}$$

---

*A heating degree day is a unit representing one degree of declination from a given point (65°F) in the mean ambient air temperature for one day. It is a standard unit reported by the U.S. Weather Bureau. For example, if the average daily temperature is 50°F, the number of heating degrees for that day is: 65°F—50°F=15.

(b) Oil

$$\frac{15{,}200 \text{ Btu/household-degree day}}{(0.60)\ 145{,}000 \text{ Btu/gallon oil}} = 0.18 \text{ gallon/household-degree day}$$

(c) Gas

$$\frac{15{,}200 \text{ Btu/household-degree day}}{(0.75)\ 1{,}000 \text{ Btu/cu ft gas}} = 22.5 \text{ cu ft/household-degree day}$$

7. Summary of estimating factors

Coal 0.0012 ton/household-degree day
Oil 0.18 gallon/household-degree day
Gas 22.5 cu ft/household-degree day
(based on 5 rooms/dwelling unit or household)

8. Sample calculation—Chicago, Illinois
(City of Chicago only)
Given data:

(a) From Census of Housing[3]

Fuel	Number of dwelling units*	*(rounded)*
Coal	458,974	460,000
Oil	332,634	335,000
Gas	346,125	350,000

(b) Average size of dwelling unit: 4/4 rooms/unit.

(c) From local climatological data,[4 5 6] the average number of annual heating degree days is 6,113.

Calculated domestic coal use

(d) Annual domestic use of coal:

460,000 dwelling units
× 0.0012 ton coal/dwelling unit-degree day
× 6,113 degree days
= 3,380,000 tons coal/year.

(e) Correction for number of rooms per dwelling unit in Chicago

$$\frac{3{,}380{,}000 \text{ tons coal}}{\text{year}} \times \frac{4.4}{5.0} = 2{,}970{,}000 \text{ tons/year.}$$

Use 3,000,000 tons coal/year.

---

*For purposes of this calculation method, the terms household and dwelling unit are used interchangeably.

9. Extension of method

In section 8, the annual domestic coal use was calculated. This calculation can be extended to the determination of fuel use by the day or month, or by heating season, by using the number degree days for those periods. This information is available for most areas.[4 5 6]

10. Accuracy of estimates

The estimates herein derived are based on averages and only approximate the true fuel use. This method yielded results comparable to those from estimates made by different methods.

REFERENCES

1. Resources in America's Future, H. H. Landberg, L. L. Fischman, and J. L. Fisher. John Hopkins Press, Baltimore, Maryland, 1963.

2. Statistical Abstract of the United States, 1962, U.S. Department of Commerce, Bureau of the Census, Washington, D. C.

3. United States Census of Housing, 1960, Final Report HC(1), No. 15, State and Small Areas, U.S. Department of Commerce (Similar Reports are available for each State).

4. (a) Local Climatological Data (Monthly) ($.10).
   (b) Local Climatological Data (Annual) ($.15).
   Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20025.

   Prices: Monthly $1.00/year including annual supplement if published. (Single copy prices noted above.)

5. Climatography of the United States No. 84, Decennial Census of United States Climate, Daily Normals of Temperature and Heating Degree Days, U.S. Department of Commerce, Weather Bureau, 1963. For sale by Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20025—$1.75.

6. Contact the local Office of the Weather Bureau, U.S. Department of Commerce.

APPENDIX D. STANDARD INDUSTRIAL CLASSIFICATIONS (SIC)

Code[a]	
20	Food and kindred products
21	Tobacco products
22	Textile mill products
23	Apparel and related products
24	Lumber and wood products
25	Furniture and fixtures
26	Paper and allied products
27	Printing and publishing
28	Chemicals and allied products
29	Petroleum and coal products
30	Rubber and plastics products
31	Leather and leather products
32	Stone, clay, and glass products
33	Primary metal industries
34	Fabricated metal products
35	Machinery, except electrical
36	Electrical machinery
37	Transportation equipment
38	Instruments and related products
39) 19)	Miscellaneous manufacturing, including ordnance

[a] Code numbers are those of the U.S. Bureau of Census.

APPENDIX E. METROPOLITAN AREAS—FUEL USE DATA

Domestic use of fuels has been allocated by census tracts (U.S. Census of Housing, 1960) for the following Standard Metropolitan Statistical Areas (SMSA). These data are available from the Technical Assistance Branch, Division of Air Pollution, Public Health Service, Cincinnati, Ohio.

Alabama	Birmingham
Colorado	Denver
Connecticut	Bridgeport
	Hartford
	Meridan
	New Britain
	New Haven
	New London-Groton-Norwich
	Norwalk
	Stamford
	Waterbury
Delaware	Wilmington
District of Columbia	Washington (and adjacent area)
Illinois	Chicago (and adjacent area)
Indiana	Gary-Hammond-E. Chicago
Maryland	Baltimore (incl. Annapolis)
Missouri	St. Louis (incl. adjacent area, Ill.).
	Munroe County, Ill.
New Jersey	Atlantic City
	Jersey
	Newark
	Patterson-Clifton-Passaic
	Trenton
New York	New York (incl. boroughs and adj. area)
Pennsylvania	Allentown-Bethlehem-Easton
	Harrisburg
	Lancaster
	Philadelphia (and adjacent area including New Jersey)
	Reading
	York
Tennessee	Nashville

APPENDIX F. EMISSION FACTORS*

INTRODUCTION

The source emission factors presented in this report were compiled primarily for use in conducting an air pollutant emission inventory. The compilation is the result of an extensive literature survey and includes emission factors for the principal combustion and industrial processes. Obviously, the best emission factor to use for any specific source of air pollution is that resulting from source tests of the specific source. Unfortunately, many urban areas are not equipped to conduct the numerous and expensive stack testing studies needed for an emission inventory. The purpose of this compilation of emission factors is to provide the best available substitute to air pollution control agencies unable to conduct extensive source test programs.

In certain cases, particularly in the combustion and refuse disposal areas, a single number is presented for the emission factor for a specific pollutant. It should be understood that the number is usually a weighted average of several different values found in the listed references. The compilation of source emission factors presented is, in our judgment, the most accurate currently available. As new technical advances are made, however, and additional emission data become available in the literature, the present compilation should be revised to reflect the newer data and developments.

SOURCE EMISSION FACTORS

AIRCRAFT EMISSIONS

Johnson and Flynn have presented emission factors, in the form of pounds of pollutants emitted per thousand gallons of fuel consumed, for jet and piston aircraft.(*1*) Revised emission factors for turboprop aircraft were also obtained.(*2*) These factors, shown in Table F1, are combined and averaged figures for emissions during all phases of aircraft operation (taxi, takeoff, climbout, approach, and landing) that take place below the arbitrarily chosen altitude of 3500 feet. It was felt that emissions taking place at cruise altitude (above 3500 feet) were not of concern to air pollution authorities.

Data were obtained for fuel consumption in the three classes of aircraft,(*2*) so that the emission factors given in Table F2 could be expressed in pounds of pollutant emitted per flight. A flight is defined as the combination of a landing and a takeoff.

ASPHALT BATCHING PLANTS

An asphalt concrete batching plant generally consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins, and conveying equipment. Sand and

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*Compiled by Martin Mayer, Technical Assistance Branch, Division of Air Pollution, U.S. Public Health Service, Cincinnati, Ohio.

Table F1 EMISSION FACTORS FOR AIRCRAFT BELOW 3500 FEET

(lb/1000 gal of fuel consumed)

Type of emission	Jet aircraft[a]	Turbo prop aircraft	Piston engine aircraft
Aldehydes	6	5	5
Carbon monoxide	56	40	2,450
Hydrocarbons	15	5	491
Oxides of nitrogen	37	23	147
Particulates	54	12	12

[a] No water injection on takeoff.

Table F2. EMISSION FACTORS FOR AIRCRAFT BELOW 3500 FEET

(lb/flight)[a]

Type of emission	Jet aircraft[b]	Turbo-prop aircraft		Piston engine aircraft	
	4 engines	2 engines	4 engines	2 engines	4 engines
Aldehydes	4	0.3	1.1	0.2	0.5
Carbon monoxide	35	2	9	74	245
Hydrocarbons	10	0.3	1.2	15	49
Oxides of nitrogen	23	1.1	5	4.4	15
Particulates	34	0.6	2.5	0.4	1.2

[a] A flight is the combination of a landing and a takeoff.
[b] No water injection on takeoff.

aggregate are charged from bins into a rotary dryer. The dried aggregate at the lower end of the dryer is mechanically conveyed by a bucket elevator to the screening equipment, where it is classified and dumped into storage bins. Weighed quantities of the sized products are then dropped into the mixer along with asphalt, where the batch is mixed and dumped into trucks for transportation to the paving site. The combustion gases and fine dust from the rotary drier are exhausted through a precleaner. This is usually a single cyclone, but twin or multiple cyclones and other devices are also used. The precleaner catch is then discharged back into the bucket elevator, where it continues in the process with the main bulk of the dried aggregate. The exit gas stream of the precleaner is usually passed through air pollution control equipment, normally scrubbers of the multiple centrifugal or baffled spray tower type.(*3*)

Dust and particulate emissions from the scrubbers usually average around 0.2 pound per ton of product produced. If no scrubbers are used, the dust and particulate emission averages around 5 pounds per ton of product produced.(*3*)

AUTOMOTIVE AND DIESEL EXHAUST EMISSIONS

The composition of automotive and diesel exhausts is characterized by greater amounts of carbon monoxide and hydrocarbons than that of emissions from other fuel burning processes. Automotive and diesel exhaust emissions, in pounds per 1,000 gallons of fuel consumed, are given in Table F3. Another way of presenting automobile emission factors is in pounds per vehicle mile.

Table F3. EMISSION FACTORS FOR GASOLINE AND DIESEL ENGINES (lb/1000 gal)

Pollutant	Gasoline engines[a]	Diesel engines[b]
Aldehydes	4	10
Benzo(a)pyrene	0.3 gram/1000 gal[c]	0.4 gram/1000 gal[d]
Carbon monoxide	2910	60[a]
Hydrocarbons	524[e]	180
Oxides of nitrogen	113	222[f]
Oxides of sulfur	9	40
Ammonia	2[f]	n.a.[g]
Organic acids	4[f]	31[f]
Particulates	11	110

[a] Includes blowby emissions, but not evaporation losses (Reference 4).
[b] Reference 5.
[c] Reference 6.
[d] Reference 7.
[e] Includes 128 lb/1000 gal blowby emissions (Reference 8).
[f] Reference 9.
[g] Not available.

CEMENT PRODUCTION

Raw materials for the manufacture of cement are ground, mixed, and blended by either a wet or a dry process. In the dry process, the moisture content of the raw materials does not exceed 1 percent; in the wet process, a slurry of carefully controlled composition is made, generally having a moisture content ranging from 30 to 50 percent. After the raw materials are crushed and ground, they are introduced into a rotary kiln that is fired with pulverized coal, oil, or gas to produce a temperature of about 2700°F. Drying, decarbonating, and calcining are accomplished as the material passes through the kiln, resulting in the formation of a cement clinker. The clinker is cooled, mixed, ground with gypsum, and bagged for shipment as cement. Dust and fume in the waste gases of the kiln are the major sources of air pollution. Gaseous pollutants, notably sulfur dioxide, are also emitted from the kiln.(*10*)

Kiln emissions for the wet process of producing cement range from 15 to 50 pounds of dust per barrel of cement produced; 28 pounds of dust per barrel of cement produced is a typical value. In the dry process, the losses range from 22 to 87 pounds of dust per barrel of cement produced; 45 pounds of dust per barrel of cement is a typical value. Control of kiln dust emissions varies considerably depending upon the type and age of the control system. Typical collection efficiencies are: 80 percent for multicyclones; 90 percent for old electrostatic precipitators; 95 percent for multicyclones plus old electrostatic precipitator systems; 99+ percent for multicyclones plus new electrostatic precipitator systems; 99.5+ percent for fabric filter units either alone or in combination with multicyclones.*(11)*

COFFEE PROCESSING

Because coffee is imported in the form of green beans, it must be cleaned, blended, roasted, and packaged before it can be sold. The essential ingredients of the roasted beans may be extracted, spray dried, and marketed as instant coffee. In the roasting of coffee, chemical changes, such as the degradation of sugars, occur that bring out the characteristic flavor and aroma of the coffee.

In the indirect-fired roaster, a portion of the roaster gases is recirculated through the combustion area for destruction of smoke and odors by oxidation in the flame. In the direct-fired roaster, all the roaster gases are vented without recirculation through the flame. Essentially complete removal of both smoke and odors can be realized with a properly designed afterburner.

In the cleaner, contaminating materials lighter than the green beans are separated from the beans by an air stream. In the stoner, contaminating materials heavier than the roasted beans are separated from the beans, also by an air stream.

In the cooler, the hot roasted beans are quenched with water, and emit large quantities of steam and some particulate matter.*(12)* Table F4 summarizes the emissions from the various operations involved in coffee processing.

COMBUSTION

Coal

The burning of coal produces several different kinds of gaseous pollutants, including carbon monoxide, nitrogen oxides, sulfur oxides, aldehydes, and hydrocarbons. The quantities of these pollutants emitted depend on the composition of the coal, the method of firing, the size of the unit, and other factors. Table F5 gives average emission factors for the gaseous pollutants in the three major categories of coal usage. As a rule of thumb, for these three categories, capacities of power plant boilers are generally above 100×10^6 Btu per hour, capacities of industrial boilers range from 10 to 100×10^6 Btu per hour, and capacities of domestic and commercial boilers are generally below

Table F4. PARTICULATE EMISSIONS FROM COFFEE ROASTING AND AUXILIARY OPERATIONS

Operation	Particulate emissions, without cyclone[a]		Particulate emissions, with cyclone[b]	
	grains/scf	lb/1000 lb green beans	grains/scf	lb/1000 lb green beans
Indirect fired roaster[c]	0.3 -0.6	0.8-4.0	0.09-0.127-0.15[d]	0.2-0.58-1.0
Direct fired roaster[c]	0.6 -0.9	3.0-5.0	0.17-0.193-0.22	0.9-1.12-1.3
Stoner, cooler cleaner, and handling systems combined	0.01-0.15	0.5-0.8	0.01-0.017-0.03	0.1-0.16-0.3

[a] Reference 13.

[b] Reference 12.

[c] Without afterburners.

[d] When 3 values are given, such as 0.09-0.127-0.15, the center value is the approximate average and the values at either end are the lowest and highest values reported.

Table F5. GASEOUS EMISSION FACTORS FOR COAL COMBUSTION[a] (lb/ton of coal burned)

Pollutant	Power plants	Industrial	Domestic and commercial
Aldehydes (HCHO)	0.005	0.005	0.005
Carbon monoxide	0.5	3	50
Hydrocarbons (CH_4)	0.2	1	10
Oxides of nitrogen (NO_2)	20	20	8
Oxides of sulfur (SO_2)	38 S[b]	38 S[b]	38 S[b]

[a] Reference 14.

[b] S equals percent sulfur in coal.

Example: If the sulfur content is 2 percent, the oxides of sulfur emission would be 2x38, or 76 lb. of sulfur oxides/ton of coal burned.

10×10^6 Btu per hour. It is generally advisable to deal with large coal-burning plants ($>100 \times 10^6$ Btu) on an individual basis.

The burning of coal also produces a particulate emission. The quantity of the emission depends mostly upon the ash content of the coal and the type of unit and control equipment used. One of the more interesting constituents of the particulate emission is benzo(a)-

pyrene, which has been shown to be carcinogenic to laboratory animals. Table F6 provides average total particulate emission factors for various types of coal-firing units without control equipment. Separate benzo(a)pyrene emission factors have been provided where available. The operation of electrostatic precipitators has no effect on the benzo(a)pyrene emission.

Table F6. PARTICULATE EMISSION FACTORS FOR COAL COMBUSTION (WITHOUT CONTROL EQUIPMENT)

Type of unit	Particulate emission,[a] lb/ton of coal burned	Benzo(a)pyrene emission,[b] µg/ton of coal burned
Pulverized - general		
Dry bottom	16A[c]	600
Wet bottom	17A[c]	
Without reinjection	13A[c]	
With reinjection	24A[c]	
Cyclone	2A[c]	6,000[d]
Spreader stoker		
Without reinjection	13A[c]	700
With reinjection	20A[c]	
All other stokers	5A[c]	100,000
Hand-fired equipment	20	12×10^6

[a] Reference 14.

[b] Reference 15.

[c] A equals percent ash in coal.

Example: If the percent ash in the coal is 10 percent, the ash emission for a cyclone unit would be 2x10 or 20 lb/ton of coal burned.

[d] Reference 16.

Table F7 gives the ranges of fly ash collection efficiencies for various types of control equipment when used on several types of furnaces. If the type of control equipment used is unknown, the uncontrolled emission factors can be refined to take into account the effect of control by using Table F8. Table F8 gives estimates of particulate emissions for "average" and "good" control. If the emission values without control from Table 6 are less than those from Table 8, the smaller number should be used. The values for average control were calculated from the present ASME Model Ordinance; those for good control are based upon a proposal being considered by the ASME Standards Committee for Emission of Smoke and Dust from the Combustion of Fuel for Indirect Heating. The proposal is still under study and has not yet been adopted.*(14)*

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Table F7. RANGES OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF FLY ASH CONTROL EQUIPMENT[a]

Type of furnace	Range of collection efficiencies, %			
	Electrostatic precipitator	High efficiency cyclone	Low resistance cyclone	Settling chamber expanded chimney bases
Cyclone furnace	65 - 99[b]	30 - 40	20 - 30	
Pulverized unit	80 - 99.9[b]	65 - 75	40 - 60	
Spreader stoker		85 - 90	70 - 80	20 - 30
Other stokers		90 - 95	75 - 85	25 - 50

[a] Reference 14.

[b] High values attained with high efficiency cyclones in series with electrostatic precipitators.

Table F8. ESTIMATES OF CONTROLLED PARTICULATE EMISSIONS[a]

Type of control	Lb particulate/ton of coal burned		
	Power plants	Industrial boilers	Domestic and commercial plants
Average	25	25	25
Good	10	15	20

[a] Reference 14.

Natural Gas

Table F9 shows the emission factors for the combustion of natural gas in power plants, industrial boilers, and domestic and commercial heating units. The calculations are based upon a density for natural gas of 0.05165 pound per standard cubic foot and a heating value of 1000 Btu per standard cubic foot.

Oil

The pollutants emitted in oil combustion are much the same as in coal combustion. Particulate emissions are considerably lower, however. As with coal, the sulfur oxide emissions vary with the sulfur content of the fuel. Table F10 gives the emission factors for large and for small sources.

Table F9. EMISSION FACTORS
FOR COMBUSTION OF NATURAL GAS[a]
(lb/10^6 ft^3 of natural gas burned)

Pollutants	Power plants	Industrial boilers	Domestic and commercial heating units
Aldehydes	1	2	negligible
Benzo(a)pyrene[b]	n.a.[c]	20,000 μg/10^6 ft^3	130,000μg/10^6 ft^3
Carbon monoxide	neligible	0.4	0.4
Hydrocarbons	neligible	negligible	negligible
Oxides of nitrogen	390	214	116
Oxides of sulfur	0.4	0.4	0.4
Ammonia	n.a.[c]	0.3[d]	0.3[d]
Organic acids	n.a.[c]	62[d]	62[d]
Particulate	15	18	19

[a] Reference 17.

[b] Reference 15.

[c] Not available.

[d] Reference 9.

Table F10. EMISSION FACTORS FOR OIL COMBUSTION[a]
(lb/1000 gal of oil burned)[b]

Pollutants	Large sources (1000 h.p. or more)	Small sources (1000 h.p. or less)
Aldehydes	0.6	2
Benzo(a)pyrene[c]	5000 μg/1000 gal	40,000μg/1000 gal
Carbon monoxide	0.04	2
Hydrocarbons	3.2	2
Oxides of nitrogen (NO_2)	104	72
Sulfur dioxide	157 S[d]	157 S[d]
Sulfur trioxide	2.4 S[d]	2 S[d]
Particulate	8	12

[a] Reference 18.

[b] Density of fuel oil equals 8 lb/gallon and there are 42 gallons per barrel.

[c] Reference 15.

[d] S equals percent sulfur in oil.

Example: If the sulfur content is 2 percent, the sulfur dioxide emission would be 2x157, or 314 lb. SO_2/1000 gal. oil burned.

CONCRETE BATCHING PLANTS

Concrete batching plants are generally simple arrangements of steel hoppers, elevators, and batching scales for proportioning rock, gravel, and sand aggregates with cement for delivery, usually in transit mixer trucks. Aggregates are usually crushed and sized in separate plants and are delivered by truck or belt conveyors to ground or other storage from which they can be reclaimed and placed in the batch plant bunkers.

By careful use of sprays, felt, or other filter material over breathers in the cement silos, and canvas curtains drawn around the cement dump trucks while dumping, dust losses can be controlled. Aggregate stocks in bunkers are wet down with sprays to prevent dusting. With careful operation, under stringent Los Angeles standards, losses in these plants can be held to about 0.025 pound of dust per yard of concrete. Uncontrolled plants have emissions of about 0.2 pound of dust per yard on concrete handled.(*19*)

FERROUS AND NON-FERROUS FOUNDRIES

The emission factors given in Table F11 are for various processes found in ferrous and non-ferrous foundries. Although the data are almost all from Los Angeles, they seem to be representative of the experience with these processes in other parts of the country. In gray iron cupolas, approximately 1725 pounds of casting are produced for each ton of raw material processed. In the electric steel melting furnace and the nonferrous melting furnaces, it can be assumed that the weight of castings produced equals the weight of raw material processed.

The control of emissions from gray iron cupolas varies depending upon the type of control equipment used. Typical collection efficiencies are: 75 to 80 percent for a high-efficiency centrifugal collector; about 40 percent for a dynamic water scrubber; 96-99 percent for a fabric filter unit; and 94-98 percent for an electrostatic precipitator installation.

GASOLINE EVAPORATION

A study of the typical pattern of motor gasoline storage and handling reveals five major points of gasoline emission. These are:

1. Breathing and filling losses from storage tanks at refineries and bulk terminals.
2. Filling losses from loading tank conveyances at refineries and bulk terminals.
3. Filling losses from loading underground storage tanks at service stations.
4. Spillage and filling losses in filling automobile gas tanks at service stations.

Table F11. EMISSIONS FROM FERROUS AND NON-FERROUS FOUNDRIES[a]

Process	Aerosol emission factor, lb/ton of raw material processed	
	Uncontrolled	Controlled
Gray iron melting cupolas (avg)	17.1	0.26[b]
Less than 48 in. I.D.	12.9	
Less than 48-60 in. I.D.	19.5	
Greater than 60 in. I.D.	18.9	
Electric steel melting furnaces (avg)	8.6	0.17[b]
Less than 5-ton capacity	10.6	
5- to 20-ton capacity	5.7	
50- to 75-ton capacity	9.6	
Melting of red brass (< 7% zinc):		
Crucible or pot furnaces	3.3	
Rotary furnaces	21.3	10.1[c]
Reverberatory furnaces	16.8	
Electric furnaces	3	
Melting of yellow brass (> 20% zinc):		
Crucible furnaces	14	5.1[c]
Rotary furnaces		22.8[c]
Reverberatory furnaces		5.7[b]
Electric induction type furnaces	0.7	
Melting of bronze:		
Crucible furnaces	3.8	
Rotary furnaces	30.6	4.7[b]
Melting of aluminum:		
Crucible furnaces	1.9	
Reverberatory furnaces	5.2	2.1[d]

[a] Reference 17.

[b] With baghouse control.

[c] Slag cover used as the only control method.

[d] With packed column scrubber and either baghouse or electrostatic precipitator as secondary collector.

5. Evaporative losses from the carburetor and gas tank of motor vehicles.

Breathing loss has been defined as that loss associated with the thermal expansion and contraction of the vapor space resulting from the daily temperature cycle. Filling loss has been defined as the vapors expelled from a tank (by displacement) as a result of filling.(*20*)

Splash and submerged fill have been defined by R. L. Chass, et al.,(*21*) as follows: "In splash fill the gasoline enters the top of the fill pipe and then has a free fall to the liquid surface in the tank. The free falling tends to break up the liquid stream into droplets. As these droplets strike the liquid surface, they carry entrained air into the liquid, and a "boiling" action results as this air escapes up through the liquid surface. The net effect of these actions is the creation of additional vapors in the tank.

"In submerged filling, the gasoline flows to the bottom of the tank through the fill pipe and enters below the surface of the liquid. This method of filling creates very little disturbances in the liquid bath and, consequently, less vapor formation than splash filling."

Emission factors are given for both cone roof and floating roof storage tanks, as well as for splash and submerged fill in tank vehicles and service station tanks. The degree to which floating roof tanks and submerged fill are utilized varies from place to place. Ideally, the gasoline evaporative emission should be calculated on the basis of the percentage of local utilization of submerged fill and floating roof tanks. If this is not known, then 75 percent floating roof tanks and 50 percent submerged fill should be assumed. The effect of vapor recovery loading arms or tank compression systems has not been considered.

An average emission factor for hydrocarbons from cone roof gasoline storage tanks is 47 pounds per day per 1000 barrels of storage capacity. For floating roof tanks storing gasoline, a typical hydrocarbon emission is 4.8 pounds per day per 1000 barrels of storage capacity. More precise values for a specific locality can be calculated by methods given in the American Petroleum Institute Bulletin 2517, entitled "Evaporation Loss from Floating Roof Tanks," and Bulletin 2518, entitled "Evaporation Loss from Fixed Roof Tanks." These are available from the American Petroleum Institute, Division of Technical Services, 1271 Avenue of the Americas, New York 20, New York.

Table F12 summarizes the emission factors for gasoline evaporation at the other four major points of emission.

IRON AND STEEL MILLS[25]

To make steel, iron ore (containing some 60 percent iron oxides) is reduced to pig iron, and some of its impurities are removed in a blast furnace; the pig iron is further purified in either open hearths, Bessemer converters, the basic oxygen process, or electric furnaces.

Table F12. GASOLINE EVAPORATION EMISSIONS

Point of emission	Lb/1000 gal of throughput	Percent loss by volume[a]
Filling tank vehicles[b]		
Splash fill	8.2	0.14
Submerged fill	4.9	0.08
50% splash fill and 50% submerged fill	6.4	0.11
Filling service station tanks[c]		
Splash fill	11.5	0.19
Submerged fill	7.3	0.12
50% splash fill and 50% submerged fill	9.4	0.15
Filling automobile tanks[d]	11.6	0.19
Automobile evaporation losses (gas tank and carburetor)[e]	92	1.50

[a] An average gasoline specific gravity of 0.73 is assumed.

[b] Reference 23.

[c] Reference 21.

[d] Reference 24.

[e] Reference 8.

Various alloying metals (chromium, manganese, etc.) are usually added to produce specialized types of steel.

Blast furnaces are charged with iron ore, coke, and limestone in alternating layers. To promote combustion, hot air is blown into the bottom of the furnace. To produce 1 ton of pig iron requires, on the average, 1.7 tons of iron ore, 0.9 ton of coke, 0.4 ton of limestone, 0.2 ton of cinder, scale, and scrap, and 4.0 to 4.5 tons of air.

Most of the coke used in the blast furnaces is produced in "by product" coke ovens from certain grades of bituminous coal. The distillation products produced are recovered for sale, and gases remaining after by-product recovery are used for heating the coke ovens and elsewhere in the plant. Smoke and gases escape only during charging and discharging operations; the rest of the process is normally air tight, but at some plants leakage of smoke and gases occurs because of poorly fitted oven doors.

Sintering plants convert iron ore fines and blast furnace flue dust into products more suitable for charging to the blast furnace. This is done by applying heat to a mixture of the iron-containing materials and coke or other fuels on a slow-moving grate through which combustion air is drawn.

In the open hearth process for making steel, a mixture of scrap iron and steel and pig iron is melted in a shallow rectangular basin or "hearth" in which various liquid or gaseous fuels provide the heat. Impurities are removed in a slag. Oxygen injection (lancing) into the furnace speeds the refining processes, saves fuel, and increases steel production. Oxygen lancing increases the amount of fume and dust produced, however.

The basic oxygen process (the LD or Linz-Donawitz process) is new to the United States, but is gaining increasing application here. In this process, oxygen is blown onto the surface of the molten bath at high velocity, resulting in violent agitation and intimate mixing of oxygen with the pig iron.

Electric furnaces are used primarily to produce special alloy steels. Heat is furnished by direct-arc-type electrodes extending through the roof of the furnace. In recent years oxygen has been used to increase the rate and uniformity of scrap meltdown and to decrease power consumption.

Bessemer converters are now seldom used. They are pear-shaped, tilting, steel vessels lined with refractory brick and clay. Impurities in the molten iron charge are oxidized by air blown through the metal for about 15 minutes.

A scarfing machine removes surface defects from the steel billets and slabs before they are shaped or rolled. This is done by applying jets of oxygen to the surface of the steel and thus removing a thin upper layer of the metal by rapid oxidation.*(25)* Emission factors for the various steel mill processes are shown in Table F13.

Table F13. EMISSIONS FROM STEEL MILLS

(From reference 26, which is based on data in reference 25)

Operation	Before control		Emission with control				Approximate volume of gases handled
	Stack loading, grains/scf	Lb/ton of product	Control used[c]	Stack loading grains/scf	Lb/ton of product	Approximate efficiency, %	
Blast furnace	7-10	200	Preliminary cleaner (settling chamber or dry cyclone)[b]	3-6		60	87,000 scfm for a 1000-ton per day furnace.
			Primary cleaner (Wet scrubber)[b]	0.05-0.3-0.7[a]	5.4	90	
			Secondary cleaner (E.S.P. or V.S.)[b]	0.004-0.008	0.1-1.4	90	
Sintering machine	0.5-3.0	5-20-100	Dry cyclone	0.2-0.6	2.0	90	120,000-160,000 scfm for a 1000-ton per day machine.
			E.S.P. (in series with dry cyclone)	0.01-0.05	1.0	95	
Sinter machine discharge-crusher, screener and cooler	6.0	22	Dry cyclone	0.4	1.5	93	17,500 scfm for a 1000-ton per day machine.
Open hearth (Not oxygen lanced)	0.1-0.4-2.0	1.5-7.5-20.0	E.S.P.	0.01-0.05	0.15	98	35,000 scfm for a 175-ton furnace.
			V.S.	0.01-0.06	0.15-1.1	85-98	
			Baghouse	0.01	0.07	99	
Open hearth (With oxygen lance)	0.1-0.6-2.5	9.3	E.S.P.	0.01-0.05	0.2	98	35,000 scfm for a 175-ton furnace.
			V.S.	0.01-0.06	0.2-1.4	85-98	
Electric arc furnace	0.1-0.4-6.0	4.5-10.6-37.8	High efficiency scrubber	0.01	0.2	Up to 98	Highly variable depending on type of hood. May be about 30,000 scfm for a 50-ton furnace.
			E.S.P.	0.01-0.04	0.3-0.8	92-97	
			Baghouse	0.01	0.1-0.2	98-99	
Bessemer converter	0.8->10	15-17-44	No practical method of control				
Basic oxygen furnace	5-8	20-40-60	V.S.	0.03-0.12	0.4	99	Varies with amount of oxygen blown. 20 to 25 scfm per cfm of oxygen blown.
			E.S.P.	0.05	0.4	99	
Scarfing machine	0.2-0.8	3 lb/ton of steel processed	Settling chamber	No data	No data	No data	85,000 scfm for a 45-inch, 4-side machine.
Coke ovens (By-product type)	No data	0.1% of coal processed (Rough estimate)	Emissions can be minimized through equipment design and operational techniques	No data	No data	No data	No data.

[a] When 3 values are given, such as 5-20-100, the center value is the approximate average and values at either end are the lowest and highest values reported. All data are highly variable depending on nature of a specific piece of equipment, materials being processed, and operating procedure.

[b] Used in series. Data on that basis.

[c] V.S. means venturi scrubber.
E.S.P. means electrostatic precipitator.

KRAFT PULP PLANTS

Before the cellulose from wood can be made into pulp, the lignin that binds the cellulose fibres together must be removed. In the kraft process, this is done by treating with an aqueous solution of sodium sulfide and sodium hydroxide. This liquor is mixed with wood chips in a large, upright, pressure vessel, called a digester, and cooked for about 3 hours with steam. During the cooking period, the digester is relieved periodically to reduce the pressure build-up of gases.

When cooking is completed, the bottom of the digester is suddenly opened and its contents forced into the blow tank. Here, the major portion of the spent cooking liquor, containing the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter, where unreacted chunks of wood are removed. The pulp is then processed through intermittent stages of washing and bleaching, after which it is pressed and dried into the finished product.

Most of the chemicals from the spent cooking liquor are recovered for reuse in subsequent cooks. The spent, "black," liquor from the blow tank is concentrated first in a multiple effect evaporator and then in a direct contact evaporator utilizing recovery furnace flue gases.

The combustible, concentrated, black liquor thus produced is burned in a recovery furnace where the inorganic chemicals, to be recovered, fall to the floor of the furnace in a molten state.

The melt, consisting mainly of sodium sulfide and sodium carbonate, is withdrawn from the furnace and dissolved with water and weak causticizing plant liquor in a smelt tank. The "green" liquor thus produced is pumped into a causticizer where the sodium carbonate is converted to sodium hydroxide by the addition of calcium hydroxide. The calcium carbonate produced is converted into calcium oxide in a lime kiln, and is slaked to produce calcium hydroxide for further use in the causticizer. The effluent solution produced by the causticizing reaction is known as "white" liquor and is withdrawn and re-used in the digestion process.

Table F14 summarizes the emissions from the various processes involved in a kraft pulp mill.(27)

MINERAL ACID MANUFACTURE

Nitric Acid

In the United States, nitric acid is produced mainly by the high-pressure catalytic reaction of vaporized, anhydrous ammonia and hot, filtered air. The resulting mixture of hot nitric oxide and air is cooled, and additional air is provided to complete the oxidation to nitrogen dioxide. The nitrogen dioxide gases are contacted with water in an absorbing tower to produce nitric acid. The major emissions are

Table F14. EMISSION FACTORS FOR KRAFT PULP PROCESSING[a, b]

(lb/ton dry pulp produced)

Source	Gaseous pollutants			Particulate pollutants	Type of control
	Hydrogen sulfide	Methyl mercaptan	Dimethyl sulfide		
Digester blow system	0.1-0.7	0.9-5.3	0.9-3.8	negligible	Untreated
Smelt tank	n.a.[c]	n.a.[c]	n.a.[c]	20	Uncontrolled
				5	Water spray
				1-2	Mesh demister
Lime kiln	1	negligible	negligible	18.7	Scrubber (approximate 80% efficient)
Recovery furnace[d]	3.6	5	3	150	Primary stack gas scrubber
	3.6-7.0	n.a.[c]	n.a.[c]	7-16	Electrostatic precipitator
	0.7	n.a.[c]	n.a.[c]	12-25	Venturi scrubber
Multiple effect evaporator	1.2	0.04	n.a.[c]	negligible	Untreated
	0 - 0.5	0.003-0.030	negligible	negligible	Black liquor oxidation
Oxidation towers	n.a.[c]	n.a.[c]	0.1	negligible	Black liquor oxidation

[a] Reference 27.
[b] Reference 28.
[c] Not available.
[d] Gaseous sulfurous emissions are greatly dependent on the oxygen content of the flue gases and furnace operating conditions.

nitrogen oxide and nitrogen dioxide. Emissions of acid mist are normally insignificant. *(29)*

Emissions of nitrogen oxides range from 30 to 100 pounds per ton of acid produced: 55 pounds of nitrogen oxides per ton of acid produced is a typical value. *(30)* Generally, 75 to 85 percent of the brown nitrogen dioxide will be reduced to colorless nitrogen oxide by a catalytic reduction unit. Because of extra fuel requirements, only about 25 percent of the total nitrogen oxides are reduced to nitrogen and oxygen by catalytic reduction. *(31)*

Phosphoric Acid

Phosphoric (orthophosphoric) acid is produced by two principal methods — the wet process and the electric furnace process. The wet process is usually employed when the acid is to be used for fertilizer production. Electric furnace acid is normally of higher purity and is used in the manufacture of high-grade chemical and food products.

In the wet process, sulfuric acid and phosphate rock are reacted in agitated tanks to form phosphoric acid and gypsum. Phosphoric acid is separated from the gypsum and other insolubles by vacuum filtration. Usually the gypsum has little market value. The phosphoric acid is normally concentrated to 50 to 55 percent P_2O_5 by evaporation. When superphosphoric acid is made, the acid is concentrated to between 70 and 85 percent P_2O_5. Emissions of gaseous fluorides, consisting mostly of SiF_4 with some HF, range between 20 to 60 pounds per ton of P_2O_5 produced. *(32)*

In the electric furnace process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorous. The gases containing the phosphorous vapors are passed through an electrical precipitator to remove entrained dust. In the "one-step" version of the process, the gases are next mixed with air to form P_2O_5 before passing to a water scrubber (packed tower) to form phosphoric acid. In the "two-step" version of the process, the phosphorous is condensed and pumped to a tower in which it is burned with air; and the P_2O_5 formed is hydrated by a water spray in the lower portion of the tower. The phosphoric acid mist formed is collected by scrubbing in packed towers. *(33)*

Emissions of P_2O_5 are in the range of 3.6 to 5.0 pounds of P_2O_5 per thousand pounds of elemental phosphorous (P_4) burned. *(34)*

Sulfuric Acid

In the United States, sulfuric acid is mainly produced by the contact process. Elemental sulfur or sulfur-bearing materials are burned in clean air that has been dried by scrubbing with sulfuric acid. Among the sulfur-bearing materials used are iron pyrites, acid sludges from refinery operations, and smelter off-gases. The sulfur dioxide produced is further oxidized to sulfur trioxide in the presence of a platinum or vanadium pentoxide catalyst. The sulfur trioxide is then contacted with 98 to 99 percent sulfuric acid to produce a more concentrated acid. The principal emissions are sulfur dioxide and sulfuric acid mist. (*35*)

The emissions of sulfur dioxide range from about 20 to 70 pounds of sulfur dioxide per ton of acid produced and are unaffected by the presence of acid mist eliminators. Figure F1 illustrates the sulfur dioxide emissions for various conversion efficiencies for sulfur dioxide. Without acid mist eliminators, emissions of acid mist range from 0.3 to 7.5 pounds of acid mist per ton of acid produced. The use of acid mist eliminators reduces this emission to some 0.02 to 0.2 pound of acid mist per ton of acid produced. (*36*)

PETROLEUM REFINERIES

A modern refinery is a maze of pipelines, valves, pumps, towers, and vessels; the entire operation can be conveniently discussed, however, in terms of four major steps — separation, conversion, treating, and blending. The crude oil is first separated into selected fractions (e.g., gasoline, kerosene, fuel oil). The relative volume of each fraction is determined by the type of crude oil used. Since the relative volumes of each fraction produced by merely separating the crude may not conform to the relative demand for each fraction, some of the less valuable separation products are converted to products with a greater sale value by splitting, combining, or rearranging the original molecules.

In the catalytic cracking operation, large molecules are decomposed into lower-boiling fractions by heat and pressure in the presence of catalysts. At the same time, some of the molecules combine to form larger molecules. The products of cracking are gaseous hydrocarbons, gasoline, kerosene, gas oil, fuel oil, and residual oil.

In catalytic reforming, gasoline is used as a feedstock and by molecular rearrangement, usually including hydrogen removal, gasoline of higher quality and octane number is produced. There are three types of reforming processes in use: fixed bed with and without catalyst regeneration, and the fluidized processes.

Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed during cracking operations. Polymerization joins two or more olefins, and alkylation unites an olefin and an iso-paraffin. Isomerization, another process used, involves rearrangement of the atoms in a molecule, usually to form branched-chain hydrocarbons.

The products from both the separation and conversion steps are treated, usually for the removal of sulfur compounds and gum-forming materials. As a final step, the refined base stocks are blended with each other and with various additives to meet product specifications and to arrive at the most valuable and salable combination of products. (*34*) Emission factors for petroleum refineries are shown in Table F15.

Table F15. EMISSION FACTORS FOR PETROLEUM REFINERIES[a]

Processes	Units for emission factors	Emission factor
A. Boilers and process heaters	Lb hydrocarbon/1000 bbl oil burned	140
	Lb hydrocarbon/1000 ft^3 gas burned	0.026
	Lb particulate/1000 bbl oil burned	800
	Lb particulate/1000 ft^3 gas burned	0.02
	Lb $\mathrm{No_2}$/1000 bbl oil burned	2900
	Lb NO_2/1000 ft^3 gas burned	0.23
	Lb CO/1000 bbl oil burned	negligible
	Lb CO/1000 ft^3 gas burned	negligible
	Lb HCHO/1000 bbl oil burned	25
	Lb HCHO/1000 ft^3 gas burned	0.0031
B. Fluid catalytic units	Lb hydrocarbon/1000 bbl of fresh feed	220
	Lb particulate/ton of catalyst circulation	1.8[b]
	Lb $\mathrm{No_2}$/1000 bbl of fresh feed	63
	Lb CO/1000 bbl of fresh feed	13,700
	Lb HCHO/1000 bbl of fresh feed	19
	Lb NH_3/1000 bbl of fresh feed	54
C. Moving bed catalytic cracking units	Lb hydrocarbon/1000 bbl of fresh feed	87
	Lb particulate/ton of catalyst circulation	4[c]
	Lb NO_2/1000 bbl of fresh feed	5
	Lb CO/1000 bbl of fresh feed	3,800
	Lb HCHO/1000 bbl of fresh feed	12
	Lb NH_3/1000 bbl of fresh feed	5

TABLE F15 (Cont.)

Processes	Units for emission factors	Emission factor
D. Compressor internal combustion engines	Lb hydrocarbon/1000 ft^3 of fuel gas burned	1.2
	Lb NO_2/1000 ft^3 of fuel gas burned	0.86
	Lb CO/1000 ft^3 of fuel gas burned	negligible
	Lb HCHO/1000 ft^3 of fuel gas burned	0.11
	Lb NH_3/1000 ft^3 of fuel gas burned	0.2
E. Miscellaneous process equipment	Lb hydrocarbon/1000 bbl refinery capacity	
1. Blowdown system		
a. With control		5
b. Without control		300
2. Process drains	Lb hydrocarbon/1000 bbl waste water	
a. With control		8
b. Without control		210
3. Vacuum jets	Lb hydrocarbon/1000 bbl vacuum distillation capacity	
a. With control		negligible
b. Without control		130
4. Cooling towers	Lb hydrocarbon/1,000,000 gal cooling water capacity	6
5. Pipeline valves and flanges	Lb hydrocarbon/1000 bbl refinery capacity	28
6. Vessel relief valves	Lb hydrocarbon/1000 bbl refinery capacity	11
7. Pump seals	Lb hydrocarbon/1000 bbl refinery capacity	17
8. Compressor seals	Lb hydrocarbon/1000 bbl refinery capacity	5
9. Others (air blowing, blend changing, and sampling)	Lb hydrocarbon/1000 bbl refinery capacity	10

[a] Reference 37.

[b] With electrostatic precipitator.

[c] With high efficiency centrifugal separator

SOLVENT EVAPORATION FROM DRY CLEANING PLANTS

Almost all dry cleaning is performed with three solvents: tetrachloroethylene, Stoddard solvent, and safety 140°F solvent. Stoddard solvent has a minimum flash point of 100°F and a distillation range of 100° to 410°F. Recently a new petroleum solvent, called safety 140°F solvent, has been introduced that has a minimum flash point of 140°F, thus lessening the explosion hazard.

Chlorinated hydrocarbons are widely used as cleaning solvents. They are nonflammable and dissolve greases and oils more rapidly, including substances not soluble in petroleum solvents. Originally, carbon tetrachloride was used, but had to be discarded because of its toxicity and corrosiveness. Trichloroethylene is less toxic and not as corrosive as carbon tetrachloride. Tetrachloroethylene (perchloroethylene) is the most widely used chlorinated dry cleaning agent. It is less toxic and less corrosive than carbon tetrachloride, and does not bleed acetate dyes as trichloroethylene does. Because it is expensive and a health hazard, tetrachloroethylene is often recovered by use of carbon adsorption beds.

Table F16 gives emission factors for chlorinated and non-chlorinated hydrocarbon dry cleaning solvents expressed in pounds per capita per day. (*38*)

Table F16 EMISSION FACTORS FOR DRY-CLEANING PLANTS[a]

	LA data[b] January 1963	BAAPCD data for 1963
Population	6,492,000	3,691,000
Tons chlor-hydrocarbons emitted/day	15	7.9
Tons petroleum solvents emitted/day	20	11.5
Total[c]	35	19.4
Tons of clothes cleaned/calendar day	158	92
Pounds of clothes cleaned/capita/year	18	18.3
Pounds of chlor-hydrocarbons emitted/capita/year	1.7	1.5
Pounds of hydrocarbon vapors emitted/capita/year	2.2	2.3
Pounds of total organic solvents emitted/capita/year	3.9	3.8

[a, b] Reference 38.

[c] 1958 data extrapolated to 1963

Table F17. EMISSION FACTORS FOR INCINERATION
(lb/ton of refuse burned)

Pollutant	Municipal multiple chamber[a]	Industrial and commercial[b]	
		Single chamber	Multiple chamber
Aldehydes	1.1	5-64	0.3
Benzo(a)pyrene[c]	6,000 μg/ton	100,000 μg/ton	500,000 μg/ton
Carbon monoxide	0.7[d]	20-200[e]	0.5
Hydrocarbons	1.4	20-50[e]	0.3
Oxides of nitrogen	2.1	1.6[e]	2.[h]
Oxides of sulfur	1.9	n.a.[g]	1.8[h]
Ammonia	0.3	n.a.[g]	n.a.[g]
Organic acids	0.6	n.a.[g]	n.a.[g]
Particulate	6[e];12[f]	20-25	4

Pollutant	Flue-fed apartment incinerator[i]	Domestic single chamber	
		Without auxiliary gas burning[k]	With auxiliary gas burning[i]
Aldehydes	5	6	2
Benzo(a)pyrene[c]	n.a.[g]	n.a.[g]	n.a.[g]
Carbon monoxide	n.a.[g]	300	n.a.[g]
Hydrocarbons	40[j]	100	1.5
Oxides of nitrogen	0.1	1.5	2
Oxides of sulfur	0.5	2.0	2
Ammonia	0.4	0.4	negligible
Organic acids	22	13	4
Particulate	26	39	6

[a] Reference 39.

[b] Reference 42.

[c] Reference 15.

[d] Reference 48.

[e] For incinerator with spray chamber. References 43-49, 51.

[f] For incinerator without spray chamber. References 41, 43, 44, 47-49, 51, 52.

[g] Not available.

[h] Reference 50.

[i] Reference 52.

[j] References 44, 47, 51.

[k] References 42, 44, 47, 52.

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REFUSE DISPOSAL AND OPEN BURNING

Incineration of Waste

Multiple chamber incinerators are made up of three refractory lined chambers in series. The first chamber, into which the combustible refuse is charged, is called the charging or ignition chamber. In the middle or mixing chamber, additional air is added to help consume any organic matter not completely burned in the ignition chamber. In the last chamber, called the combustion or expansion chamber, the combustion of gaseous organic materials is completed and the greater part of the flyash is settled out. This chamber is sometimes equipped with sprays and wetted baffles that reduce flyash emissions further, but have little effect on gaseous emissions.

Single chamber incinerators are generally simple contrivances, consisting of a firebox, door, grate, and flue. Emissions are generally high, but can be significantly reduced with auxiliary gas afterburners. Table F17 gives emission factors for the common types of municipal, industrial, commercial, apartment, and domestic incinerators.

Open Burning

Open burning, whether in dumps or in very simple backyard contrivances, gives rise to emissions that are extremely variable and difficult to measure. Dump fires generally smolder and burn less efficiently than backyard fires and thus have somewhat higher emissions. The data for backyard burning were derived from tests on burning a mixture of 50 percent newspapers and 50 percent grass clippings. Table F18 gives factors for burning dumps and for backyard burning.

Table F18. EMISSION FACTORS FOR OPEN BURNING
(lb/ton of refuse burned)

Pollutants	Burning dump[a,b]	Backyard burning[c]
Aldehydes	4	3.6
Benzo(a)pyrene[d]	250,000 μg/ton	350,000 μg/ton
Carbon monoxide	n.a.[e]	n.a.[e]
Hydrocarbons	280	280
Oxides of nitrogen	0.6	0.5
Oxides of sulfur	1.2	0.8
Ammonia	2.3	1.6
Organic acids	1.5	1.5[f]
Particulate	47	150[g]

[a] 3 pounds per capita per day of refuse burned is assumed.

[b] Reference 47.

[c] Reference 41.

[d] Reference 15.

[e] Not available.

[f] References 40, 41, 47, 52.

[g] Reference 52.

Uncontrolled Automobile Body Burning

The emission of particulates from the uncontrolled burning of automobile bodies would be about 10 pounds of particulates per automobile burned. *(53)*

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